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PUBLIC LIGHTING BY GAS & ELECTRICITY.

PUBLIC LIGHTING

BY

GAS AND ELECTRICITY.

BY

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PREFACE.

THE scheme of the present work has been to collect together a series of representative facts relating to the production and utilisation of light for public use, whether by means of coal gas or electricity. In such a connection auxiliary methods, such as the use of acetylene and petroleum, could not be passed over, and therefore are included. It would have been impossible to comprise full details of all adjuncts relating to these several subjects within the compass of a volume of the present size, and therefore much interesting matter has necessarily been left out, but it is hoped that the essential features have been indicated with sufficient clearness. The reader who desires to follow the various processes involved in the production of either coal gas or electricity, after reading the introductory accounts herein given, will doubtless continue their study in the more strictly technical text-books. The accounts given of the results of actual working operations will, it is believed, be of no little interest, particularly the full information afforded in the valuable reports by Mr. Bellamy, City Lighting Engineer of Liverpool, whose work in this direction has deservedly gained the approbation of all those who have followed its progress. Probably in no other town has public lighting been more successfully and economically studied and carried into effect. The particulars relating to the progress which has been made in the production and utilisation of electricity is well exemplified in the case of Bristol, where the important factor of the "day-load" has received much attention, resulting in a striking success.

A feature of the present work which will, it is hoped, be of much assistance to those having charge of public lighting is the valuable series of tables, giving full particulars of the systems employed in a large number of representative towns both in America and England. The author has to express his sincere thanks to the various authorities referred to, who have in every case kindly revised the proof sheets, thereby bringing them up to date and ensuring their correctness. Sincere thanks are due to those gentlemen who have kindly supplied illustrations for the work and assisted with much valuable information, particularly to Mr. G. E. Moore, M. Inst. Mech. E., Mr. T. Glover, Mr. T. Fairley, Mr. H. Leicester Greville, Mr. W. Sugg, Mr. Trotter, Mr. Bellamy, Mr. MacKean, Mr. Hammond, The Brush Electrical Engineering Company, Mr. H. Faraday Proctor, Messrs. Siemens Bros., The General Electric Company, Mr. F. H. Medhurst, Mr. W. C. Hawtayne, Mr. H. Collings Bishop, Mr. H. E. Baker, the Editors of *The Electrical Review, The Electrical Engineer, The Journal of Gas Lighting,* the Society of Chemical Industry, the Council of the Institution of Civil Engineers, and many others, for which due acknowledgment is given under the respective headings. The author also desires to acknowledge the valuable services of his chief assistant, Mr. R. G. Grimwood, F.I.C., &c., in connection with the correction of proofs, &c.

PUBLIC LIGHTING BY GAS AND ELECTRICITY.

INTRODUCTION.

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AMONGST the more important scientific discoveries which ripened during the past century into active agents for the daily benefit of man, artificial illumination by gas and electricity necessarily takes its place, being one of the chief factors in our modern civilisation. Not only has it assisted in prolonging the hours of both work and pleasure, but it is also one of the chief agents in diminishing crime in our crowded cities. It is a well-known fact that where streets and places of public resort are thoroughly well illuminated crime becomes a vanishing quantity.

Light is a form of energy produced by either chemical or mechanical processes, and may consequently be derived from natural sources of energy, such as a waterfall, or by the combustion, *i.e.*, combination with oxygen, of "fuel" either in the cells of a voltaic battery or in a furnace. It matters not whether this fuel be metal in the former, or coal or wood in the latter instance. The energy developed on being converted into the electric current is capable of producing light by passing between carbon points, or by heating to a state of incandescence solid bodies such as carbon, platinum, &c.

The first to produce the electric arc light was Sir Humphry Davy, who, in 1810, showed that when a battery of 2000 plates was connected by wires to charcoal points, bright sparks were emitted on those points being brought into contact. On these points being slowly withdrawn from each other, constant passage of the electric current took place, with the result that a brilliant electric arc light was obtained. This startling result was immediately closely investigated by the great chemist, who found that minute fragments of carbon were being constantly transferred from one carbon electrode to the other, and that the light was produced by these carbon fragments raised to an intense heat by the electric discharge. This remarkable and pregnant discovery may be considered as the starting point of the present perfected condition of electric lighting.

Perhaps it would be difficult to find a more fitting commentary upon these early discoveries than is contained in the following remarks of the late Mr. Denny Lane, the well-known gas engineer, who, in his presidential address to the Gas Institute in 1893, said:—

"In the generation of electricity from mechanical force an enormous advance has been made since the time when, over eighty years ago, this 'new planet' first 'swam into the ken' of the great philosopher, and what is most remarkable is the fact that this marvellous growth was derived from his small laboratory experiments. First of all, Oersted, in 1819, discovered that a magnetic needle suspended on a pointed pivot was deflected if an electric current was passed through a wire in its vicinity, and parallel to it; and thus electricity produced mechanical movement. It seems strange that no one thought of trying the converse — namely, whether moving the magnet mechanically would produce a current in the wire—until 1831, when Faraday made his great discovery that, in a conductor moved into or out of a magnetic field, a momentary current was produced as it crossed what he called the 'line of force.' Everything that has been done since then, by Siemens, Gramme, Wilde, Wheatstone, Ladd, and others, is but the natural growth of the seed that germinated in the fertile soil of Oersted's and Faraday's intelligence. And what a growth it has been. The telegraph, the electric light and traction, and the transference of power for over 100 miles, conversations carried on between two people separated by hundreds of miles, electrometallurgy, the separation of rare metals from their matrices, and the thousand offices performed by this deft and willing servant of man. When your practical man scoffs at what he calls the toys of science, let him reflect on the momentous issues of these two simple experiments. In the whole history of practical science nothing is so amazing as the development of dynamo-electric energy."

Following the experiment of Davy, the first practical application of his discovery was the introduction of the electric light in the original form in which he produced it. Improvements were made with the view of steadying the light, but these were more in the nature of accessories than improvements. It was not until some twenty years back that a marked departure was made, when Jablochkoff arranged the two carbon rods parallel to each other, and made use of an alternating electric current to ensure equal rates of consumption of the two points of the rods.

After extensive trials on the Continent, particularly in Paris, it was tried publicly in London by the Metropolitan Board of Works for illuminating the Thames Embankment from Westminster to Blackfriars Bridge. So little was then known of the capabilities of the new system, that the suggestion to light such a length of the Embankment from a central generating station placed under the railway bridge crossing the Embankment at the end of Northumberland-avenue was met with considerable derision; even those in charge of the experiment were not a little nervous for fear that the current would not be strong enough at the terminal lamps to enable them to start and maintain the arc. As many will remember, the experiment was a great success, and continued to illuminate the beautiful carriage way and river front of the late Sir Joseph Bazalgette's great work for several years.

No great progress was, however, immediately made. Brush and others improved the regulating arc lamp, but they left it an arc lamp still. For many purposes the light was too powerful, and when it was reduced by suitable shades and globes, the cost of the actual light utilised became prohibitive, with the result that beyond a few railway stations and prominent places of public resort, it found few patrons.

The difficulty was the division of the light, and, like so many other difficulties, no sooner was this keenly realised than it was solved. When the Thames Embankment experiments were undertaken, viz., 1880, the problem was to so place the lights that there should be a fairly even illumination on the pavement without incurring too great an expense by an excessive number of lights, and many suggestions were made to meet the difficulty.

When the system of the electric incandescence of a carbon filament was introduced by Edison and Swann, both working independently, it was at once recognised as a complete solution of this problem, and the downfall of the gas companies was anticipated in the very near future. The new light filled a great want in reference to the illumination of confined and badly-ventilated rooms, and rapidly took its place in the popular favour. The improvements, however, which have been made in arc lamps are so great that their use is extending largely; a fact which is not surprising when it is considered that, roughly speaking, the arc lamp is, light for light, only about one-tenth as costly as that of the incandescent electric lamp.

This fact, however, is not a little vitiated by the great reduction which the light of the arc, as generally used, undergoes by the interference of the rays by the globe surrounding the carbon, which in some cases will cut off as much as 60 per cent. of the initial light yielded. In this connection it is worthy of note that the original estimates of the electricians as to the candle-power of the arc lamps were most misleading. Lamps which afforded no more than 450 candles without globes were called "1000-candle lamps," but the effective light from these, after they were fitted with globes, was only some 250 candles, and even as low as 150 candles when opal globes were employed.

In a similar manner, but not to so great an extent, the electrician's estimate of the luminous intensity of the incandescent electric lamp was also over-stated. In the course of the present work this question will be fairly dealt with on the basis of actual estimations made by the writer, as well as of the current required to produce a given degree of illuminating power.

The basis upon which the value of the electric current, and consequently that of the light and power supplied, is fixed, is a subject for careful consideration. In this country the Board of Trade unit is adopted. This term indicates *quantity*, expressed in "ampères" multiplied by *intensity* expressed in "volts." Thus, a Board of Trade "unit" may be 1000 ampères multiplied by 1 volt, or 1 ampère multiplied by 1000 volts; or 10 ampères by 100 volts, &c. In each case the flow of electric energy is equal to 1000 watts; and this 1000 watts, or 1 kilowatt, acting during 1 hour, equals one Board of Trade unit. If the quantity (ampères) and the intensity (volts) required to yield a given volume of light be known, the conversion of these factors into terms of Board of Trade units can readily be made, and consequently the cost of the lights ascertained at the current price fixed for the supply of electric energy.

Having paid the latest comer the compliment of priority in the discussion, we may now turn to some considerations respecting the introduction, manufacture, supply, and use of gas. For this purpose probably no better guidance can be followed as to the early history of this industry than that of Frederick Accum, lecturer on practical chemistry, &c., who in 1815 published "A Practical Treatise on Gas Light." The great difficulty which the early advocates of this new system of artificial illumination experienced is well indicated by the following passage in his " Introductory Remarks " :—

" The scheme of lighting houses, streets, and manufactories, by means of the inflammable gas, obtainable by distillation from common pit coal, professes to increase the wealth of the nation, by adding to the number of its internal resources, and on this ground it is entitled, at least to a candid examination. The apparent slight that has been thrown upon this new branch of civil economy by some individuals, who appear to be incapable of judging of its nature, has contributed to deter sensible and well-disposed persons from wishing it success. It is the more necessary to state this fact, because when a mistaken notion once becomes diffused concerning the nature of a new project, persons of the best intentions are liable to become affected with wrong impressions on their mind."

History repeats itself. These words, written nearly a century ago, may be applied equally to many important matters at present under discussion.

The discovery and introduction of coal gas is described by Accum in the following "Sketch of the Rise and Progress of the Discovery and Application of Coal Gas as a Substitute for Procuring Artificial Light ":—

" To assist the reader in comprehending the nature and object of substituting coal gas for tallow or oil, for the purpose of obtaining light, it may be proper to touch slightly upon the successive discoveries that have been made as to the decomposition of coal, and the application of its different ingredients. Such a sketch will add to the many examples that occur in the history of science and art, showing the slow progress of mankind in following up known principles, or extracting from acknowledged facts every possible advantage.

" In the ' Philosophical Transactions ' of the Royal Society, vol. xli., so long ago as the year 1739, is recorded a paper, exhibiting an account of some experiments made by

Dr. James Clayton, from which it appears that the inflammable nature of coal gas was then already known. Dr. Clayton, having distilled Newcastle coal, obtained, as products of the process, an aqueous fluid, a black oil, and an inflammable gas, which he caught in bladders, and by pricking these he was enabled to inflame the gas at pleasure.

"It is further known that in the beginning of the last [*i.e.*, eighteenth] century, Dr. Hales,* on submitting pit coal to a chemical examination, found that during the ignition of this fossil in close vessels, nearly one-third of the coal became volatilised in the form of an inflammable vapour. Hence the discovery of the inflammable nature of coal gas can no longer be claimed by any person now living.

"In the year 1767, the Bishop of Llandaff† examined the nature of the vapour and gaseous products evolved during the distillation of pit coal. This learned philosopher noticed that the volatile product is not only inflammable as it issues from the distillatory vessel, but that it also retained its inflammability after having been made to pass through water, and suffered to ascend through two high curved tubes. The solid matters obtained by this venerable prelate were an ammoniacal fluid, a tenacious oil resembling tar, and a spongy coal or coke."

Coal gas was also discovered by a Belgian, Jean Pierre Minkelers, professor at the University of Louvain, on October 1st, 1784. Aërostatics had just come to the attention of inventors. In 1783 Dr. Charles sent up the first balloon at Paris filled with pure hydrogen gas. But hydrogen was too expensive, and investigations were continued. At the request of the Duke of Arenberg, Minkelers devoted himself to it. All substances of vegetable origin gave gas, and he tried a large number of them. "Finally, on October 1st, 1784," he wrote in his "Memoire sur l'air inflammable trié de différentes substances" (a pamphlet printed the same year, which removes all question as to date), "having placed the coal in a gun barrel, I obtained inflammable air in abundance and very promptly. Four ounces of coal gave me a cubic foot, French measure, of this air, which being weighed was found to be four times lighter than atmospheric air."

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* "Vegetab. Statics," vol. i.

† Watson's "Chemical Essays," vol. ii.

Dr. W. Henry, of Manchester, has published the following account* of Murdoch's discovery and practical application of coal gas:—

"In the year 1792, at which time Mr. Murdoch resided at Redruth, in Cornwall, he commenced a series of experiments upon the quantity and quality of the gases contained in different substances. In the course of these he remarked that the gas obtained by distillation from coal, peat, wood, and other inflammable substances burnt with great brilliancy upon being set fire to; and it occurred to him that by confining and conducting it through tubes it might be employed as an economical substitute for lamps and candles. The distillation was performed in iron retorts, and the gas conducted through tinned iron and copper tubes to a distance of 70ft. At this termination, as well as at intermediate points, the gas was set fire to as it passed through apertures of different diameters and forms, purposely varied with a view of ascertaining which would answer best. In some the gas issued through a number of small holes like the head of a watering-can; in others it was thrown out in long thin sheets; and again in others in circular ones, upon the principle of Argand's lamp. Bags of leather and of varnished silk, bladders, and vessels of tinned iron were filled with the gas, which was set fire to and carried about from room to room, with a view of ascertaining how far it could be made to answer the purpose of a movable or transferable light. Trials were likewise made of the different quantities and qualities of gas produced by coals of various descriptions, such as the

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* Thompson's "System of Chemistry," vol. i., page 52.

Swansea, Haverfordwest, Newcastle, Shropshire, Staffordshire, and some kinds of Scotch coals.

"Mr. Murdoch's constant occupations prevented his giving further attention to the subject at that time, but he again availed himself of a moment of leisure to repeat his experiments upon coal and peat at Old Cumnock, in Ayrshire, in 1797, and it may be proper to notice that both these and the former ones were exhibited to numerous spectators, who, if necessary, can attest them.

"In 1798 he constructed an apparatus at Soho Foundry, which was applied during many successive nights to the lighting of the building; when the experiments upon different apertures were repeated and extended upon a large scale. Various methods were also practised of washing and purifying the air to get rid of the smoke and smell. These experiments were continued with occasional interruptions until the epoch of the peace of the spring of 1802, when the illumination of the Soho manufactory afforded an opportunity of making a public display of the new lights, and they were made to constitute a principal feature in that exhibition.

"In the year 1803 and 1804, Mr. Winsor exhibited at the Lyceum in London the general nature of this new mode of illumination, though the machinery for procuring and the manner of purifying the gas he kept a secret. He exhibited the mode of conducting the gas through the house, and a number of devices for chandeliers, lamps, and burners, by which it might be applied. Among these he proposed long flexible tubes suspended from the ceiling or wall of the room, and at the end communicating with burners or lamps of different kinds. This gentleman showed also by experiment that the flame of the gaslight produced no smoke; that it was not so dangerous as the flame of candles or lamps; that it could not produce sparks; and that it was not so readily extinguished by gusts of wind or torrents of rain."

It will thus be seen that the early introduction of coal gas was due not only to the efforts of one individual, but to the successive work of many. The palm, however, for placing the system in a practical form has been accredited to Murdoch, who, it will be seen from the foregoing, steadily persevered until he finally accomplished the work by his display at Soho.

In order to utilise gaseous matter either as a fuel or as a light-giver, it must, like electrical energy, be conveyed from the point of generation to the place where it is to be utilised.

Electricity is conveyed by wires or copper bands; gas is forced through a pipe. If we want to pass more gas through a given-sized pipe, we must send it at a greater pressure; but if the pressure cannot be increased, we must employ a larger pipe. In order to obtain more luminous energy we must use a larger quantity of gas, but that quantity is unavailable unless it has sufficient pressure behind it to cause it to pass through the orifice of the burners, just as the electric current must have sufficient *voltage* or pressure to enable it to overcome the resistance of the carbon, and so raise it to its light-giving temperature. We may thus consider that, in the transmission of gaseous or of electrical energy, the size of pipes and the degree of pressure in the first instance may be compared with the carrying capacity of the wires (in *ampères*) and the pressure of the current (in *volts*) in the second instance.

When examining a gas supply we not only observe the pressure, which is indicated by the height, in inches, of a column of water supported by it, but its illuminating constituents, which for practical purposes are best indicated by the quantity of light which a given volume of gas is capable of affording, when it is burnt under certain specified conditions. This quality of the gas is known as its *illuminating power.* Now, what is the property pertaining to electrical energy equivalent to the chemical composition of coal gas in regard to its influence on illuminating power? It is, essentially, the pressure or *voltage*; because, although the quantity of current supplied may be constant, any falling off in the pressure is followed by a far more rapid diminution of the light given by any specified lamp. Thus a 16 candle-power lamp was found to give 15·03 candles when the current indicated 99·33 volts and 0 628 ampères, equal to 62·38 watts. When the voltage fell from 99 to 96 the loss in candle-power was from 15 to 10·9, or 27·3 per cent.; and when it fell to 90, the loss of candle-power was exactly 50 per cent. But the number of watts (volts × ampères) by which the value of the current to the consumer is estimated did not fall in proportion, but only from 62 to 56½, or about 9 per cent. The great importance of the voltage being kept fully up to the standard point is, indeed, of far more consequence to the consumer than is that of the illuminating power of the gas being equally up to its standard; and wherever an installation of the electric light is introduced, the suppliers should be under most stringent regulations as to the voltage of the supply.

The means by which the energy, either gaseous or electrical, is to be utilised, next invite consideration. These are:—(1) Burners, which may be divided into three classes, viz., ordinary, such as flat flames, Argands, &c.; recuperative, such as the Wenham and others of that type, first introduced by Herr F. Siemens; and incandescent, such as the Welsbach. (2) Electric lamps, which may be divided into two classes, viz., incandescent and arc lamps. For our purpose we may compare ordinary flat-flame, &c., gas burners with incandescent lamps, and recuperative and incandescent gas burners with arc lamps. The relative practical value of these different systems will be dealt with later on.

One of the great advantages, however, of the electric light, especially in the form of the incandescent filament, is the prevention of the vitiation of the atmosphere, and for certain purposes it cannot be doubted but that this valuable property outweighs other considerations. This fact is also of the greatest importance in regard to its use as a heating agent whether for cooking or industrial uses. Unfortunately, at the present time the cost of the current is prohibitive in regard to its general employment for these purposes, but they may become factors not to be overlooked. With regard to the degree of superiority which the electric light possesses over gas and oil flames in the important matter of heating effect on the surrounding atmosphere, Professor Nicholls states that the latter deliver to the room about 1000 gramme-calories of heat per minute for each candle-power of 3·6 gramme-calories of luminous radiation. An incandescent lamp of 5 per cent. net efficiency delivers only 72 gramme-calories per candle-power. Mr. Merritt, of the Cornell University, concludes, from experiments made by Dr. Thomson* some twenty-five years ago, and since repeated by himself, that the true efficiency of an oil lamp as a light-making machine is only about 0·3 per cent., or one-tenth of that of an incandescent lamp; and that the latter, although an immense improvement upon gas and lamps, is still far from being perfect in this respect. Doubtless, as he says, this is a question which merits the serious attention of investigators.

When considering the merits of a scheme for introducing the electric light into small towns, the initial difficulty of inducing residents to incur the expense of wiring their houses must not be overlooked; and no project should be taken in hand until this point is fairly faced.

When the electric light first began to find its way into favour as a public illuminant, many persons expressed some fear lest the peculiar character of its rays might be injurious to the eyesight of those constantly at work by its aid, during the winter months especially. Experience has now elicited the fact that there is no evidence of injury from this cause. Another point was also debated with no little force, viz., the relative diffusive power of the rival illuminants. While the superior power of the arc light enabled it to hold its own in competition with all others for outdoor illumination in this respect for a time, the recently-improved high-power incandescent gas mantles are again calling attention to this point.

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* Julius Thomson, "Das Mechanische Æquivalent des Lichtes," Pogg. Ann. cxxv., page 348.

It is true that the introduction of the Welsbach incandescent mantle has thrown back the incandescent electric light very considerably, but it remains to be seen whether the electricians will be able to improve the incandescent glow lamp to such an extent as to outstrip its rival. This may yet be done by toughening the carbon filament to such a degree that it can successfully stand a higher voltage than at present, in which case greater intensity of light can be readily obtained by increasing the voltage of the current. It is well known that a 16-candle electric incandescent lamp may be raised to 100 candles by increasing the strength of the current, but the life of the lamp is shortened from hundreds or thousands of hours to only a few minutes by reason of the breaking of the carbon filament. A most interesting feature of the electric arc is the property of enabling a light to be readily obtained which is more or less comparable with daylight in character, and therefore especially valuable when it is desired to differentiate colours.

Whether or not the time will come when the intensity of the electric incandescent lamp will be readily varied under normal conditions of current, thus raising its actinic value, must be an open question; but undoubtedly it would be of immense advantage if it were possible to raise the temperature of the filament for temporary purposes, until it yielded that quality of light which we know it is capable of doing under favourable circumstances, viz., affording a light sufficiently pure for distinguishing delicate colours.

The character of the light obtained from the arc, as well as from the electric incandescent lamp, has been made the subject of very extensive study, especially by Professor Nicholls, of the Physical Laboratory of the Cornell University in America, who has followed the original work in this direction of Otto Schumann and others. In the course of these researches it was demonstrated that the efficiency, or ratio, of the energy of the luminous radiation of the arc lamp to that of the total radiation, luminous and non-luminous, in the horizontal plane, was found to be exceedingly small—varying from about 5 per cent. to a little less than 15 per cent., the ratio increasing as the diameter of the carbons decreased. In the case of the incandescent lamp at the normal temperature of incandescence, where the intensity lies in the neighbourhood of sixteen candles, the efficiency does not rise above 5 or 6 per cent. Continuing, Professor Nicholls says:—"Since the ratio of total radiation to light-giving radiation increases but slowly, as the temperature of the radiating body rises, the efficiency is not likely to be increased in any very marked degree until we shall have learned how to suppress altogether those long waves which yield us dark heat, and are able to limit the vibrations of our source of light to that brief octave which comprises the wave-lengths to which alone the human retina responds. Whether this great step is to be made by robbing the glow-worm and the fire-fly of the secret, as has been suggested by the Director of the Sibley College of Mechanical Engineering, or by other means, we know not." Mr. Thurston's remarks to the above effect were as follows:—"The second of the greatest inventors is he who will teach us the source of the beautiful soft beaming light of the fire-fly and glow-worm, and will show us how to produce this singular illuminant, and to apply it with success practically and commercially."

Mr. Thurston claims that the dynamo-electrical engineer has nearly solved the problem. Doubtless, he overlooked the fact that Davy and Faraday were chemists.

With regard to the relative spectra of the two classes of illuminants under discussion, we may refer to the work of Dr. Julius Thomsen, Professor Nicholls, Captain Abney and Colonel Festing, and others. In the first place, it was found that the light of the candle, oil, and gas flames, and incandescent electric lamps maintained at normal candle power, although subject to considerable fluctuations from variations of the conditions under which combustion occurs, differ but slightly in quality one from the other. The incandescent material in all is carbon; and it is a significant fact that the average temperature of incandescence is nearly the same in all luminous flames, and that the highest temperature—at any rate, until very recently—at which it has been found practicable to maintain the carbon filament of the glow lamp is very nearly that at which the same material exists under most circumstances in oil and gas flames. Passing to other sources of illumination, such as the limelight and the electric arc, we find the entire portion of the spectrum lying beyond the yellow increasing more rapidly—regions of longer wave length than the yellow increasing less rapidly than the candle power, and the rate of increase growing steadily as the wave length diminishes from the red to the violet end of the spectrum.

Luminosity is the factor which we must take into account in seeking a complete expression for the efficiency of any source of illumination; and the method to be pursued in the determination of the luminosity must depend upon the use to which the light is to be applied. If we estimate light by its power of bringing out the colours of natural objects, the value which we place upon the blue and violet rays must be very different from that which would be ascribed to them if we consider merely its power of illumination, as applied to black and white. In a picture gallery, for instance, or upon the stage, the value of an illuminant increases with the temperature of the incandescent material, out of all proportion to the candle power; whereas candle power affords an excellent measure of the light to be used in a reading-room.

The luminosity of the blue and violet rays is so very small that, in the production of candle power, the influence of the very rapid growth of this end of the spectrum with increasing temperature of the lamp is scarcely appreciable. If we estimate the light-giving value of the different portions of the spectrum by means of the facility with which we can distinguish black characters upon a white ground, the importance of the more refrangible rays is still further diminished. Thus, Macé de Lepinay and Nicati have shown that, if yellow and blue light, estimated to be of equal brightness by photometric means, are of such intensity that one can clearly distinguish a printed page when illuminated by the yellow, the same page will be entirely illegible when the blue light alone falls upon it. These observers conclude, indeed, that "the mere distinguishing of objects is due almost exclusively to the illumination produced by the less refrangible parts of the normal spectrum;" so that at equal brilliancy "the superiority of yellow sources of light (luminous gas flame, incandescent lamps, &c.) over sources richer in blue rays (such as the light of the electric arc) is incontestable." "The one great advantage," they add, "upon the side of the light from the electric arc is when one desires to rehabilitate objects more nearly in the lines which they present in the light of day." This single advantage is one of which it is impossible to take due account numerically in an estimate of the efficiency of artificial illumination. It is nevertheless a most important factor in determining the adaptability of a light to nearly all the purposes of everyday life.

In the course of a discussion before the American Institute of Electrical Engineers, Professor Nicholls pointed out that if we have three incandescent electric lamps of different sizes, but each subjected to such a current as is required to give sixteen candles by the photometer—the largest lamp having the smallest current, and the smallest lamp the greatest current—they would vary in total luminous energy and in total light-giving value as measured by their luminosity.

In the smallest lamp with the strongest current the red rays would be the weakest, and the blue rays would be correspondingly the strongest. If we know the state of incandescence and the temperature of the radiating surface, we have a complete definition of the performance of a lamp, and we can then express exactly what it will do for any purpose for which it is designed. If we want colours, we use it at a high incandescence. If we want the greatest possible reading power, we shall get a maximum for that purpose at a low temperature.

CHAPTER I.

ARTIFICIAL LIGHT, ITS SOURCE AND MEASUREMENT.

General Considerations.—The necessities of modern civilisation having to so large an extent turned night into day both in the working world as well as in that of the world of pleasure and social intercourse when the day's work is done, a state of things has arisen in which artificial illumination holds the very first place, as without it the whole scheme of present-day society would at once fall to the ground. It is therefore with no hesitation that the author proposes to deal with the question with a view to placing before his readers, in as clear and succinct a manner as the subject will permit, the main facts relating to the production and use of artificial illuminants.

The numerous sources of artificial illumination now at the disposal of the public, both for indoor as well as outdoor illumination, are so varied, both in regard to their number, quality, and source, that it is impossible to adequately describe them and their respective qualities in a limited compass. Between the humble tallow candle to the intense light of the arc lamp there is a wide difference. Between these two extremes we have a number of sources of artificial illumination suitable for every sort and condition of circumstance which can possibly arise. We can well understand the perplexity of the inquirer who attempts for the first time to ascertain the most suitable degree and kind of illumination for any particular purpose. If the use to which the light is to be put is to show the colours of pictures or decorations, he will prefer a different light to that which he would require if he desired merely to show the way about in dark weather, whilst for the quiet reader a subdued yet sufficient light withal will be necessary.

Light Sources.—Artificial light may be obtained from candles of different construction, such as those made with tallow, in a more or less purified condition; wax, both that from the beehive and that from the paraffin series of hydrocarbons, better known as "mineral wax;" spermaceti, &c. Proceeding upwards in the scale from these there are the different kinds of oils, vegetable, animal, and mineral, viz.:—colza, cotton-seed, rape, castor, and many others, which are all suitable for the purposes of illumination under conditions of proper combustion; sperm, neatsfoot, and lard oils, &c.; whilst under the head of mineral oils we have the various petroleum oils known as petroleum, paraffin, kerosene, benzoline, shale oil, &c. Next in order to these are the gaseous class of illuminants, foremost of which stands coal-gas; then gases produced by the destructive distillation of organic bodies other than coal, such as shale, oil, waste organic *débris*, &c.; the action of superheated steam on incandescent carbon, forming the gaseous product known as water-gas; Acetylene, &c. Next we have the various forms of electric light which, in the opinion of many, is ultimately destined to displace all competitors in the race for popular favour. With these different sources of illumination it is possible to obtain, as required, light varying in intensity from a fraction of a standard candle to many thousand such candles; and, by the judicious use of lenses, to throw the rays so obtained in any given direction with an intensity equal to many millions of candles, thus forming the powerful beam of the lighthouse or that of the search-light.

This consideration naturally leads us to the question of the means of ascertaining the power of any light which it may be desired to employ. The process by which the actual intensity of any given light is ascertained is that known as photometry, or light measurement. No matter what the source of light may be, the principles involved are precisely the same, and it will be as well to clear the ground on this point completely before proceeding to other considerations.

Photometry, or the Measurement of Light: Law of Inverse Squares.—The first law of photometry is that of inverse squares. Light proceeds from a given radiant in all directions in straight lines. Consequently, as these lines proceed farther from the starting point, they separate more and more, and thus a less intensity of light impinges upon a given point the more remote its distance may be, and this reduction is in inverse ratio to the square of the distance. The following diagram will help the student to comprehend this fundamental law.

Let it be assumed that the four diverging lines in the following (Fig. 1) represent the rays proceeding from a light placed in the centre of a hollow sphere having a radius of one foot. At that distance a certain number of the rays enclosed within the lines will illuminate a space on the interior of the hollow sphere. If, now, the shell be removed and another having a radius of 2ft. be put in its place, then the rays which were concentrated upon the space on the inner surface of the smaller shell will now illuminate a surface equal to four times that size on the larger shell, and therefore the intensity per unit surface at twice the distance is one-fourth, or inversely to the square of the distance. In the same way, if still larger shells, or, what is the same thing, sections of shells,

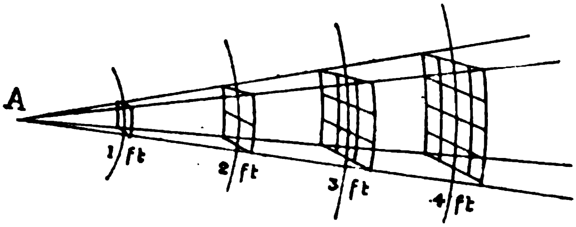


Fig. 1.

be placed in position, having the respective radii of 3ft. and 4ft., it will be seen that the same rule obtains. This is a simple point, but in experimental work, away from the regulation instruments, it is absolutely necessary to clearly comprehend it.

The next step is to employ some means of estimating the intensity of the light received upon a given surface. This has been the subject of very numerous experiments with the view of ascertaining the best, especially as the advance of scientific accuracy accompanied by the legal necessities in relation to the infliction of penalties for failure to comply with statutory requirements, has drawn the line of demarcation between "good" and "bad" closer and closer until, at the present time, differences in the estimation of a light source to the extent of only a fraction of a percentage will involve legal penalties.

Comparison of two Lights.—The first attempt at the measurement of the degree of illumination of which we have any record is Marie's obscuration method, in which he employed successive pieces of glass until he extinguished the rays from the light under examination, and then estimated the intensity of the light by the number of pieces of glass required. In 1735 Celsius observed the distance at which small objects became invisible. Bouguer twenty-five years afterwards employed discs of tissue paper, which covered circular holes in an upright piece of pasteboard, which had a second upright piece at right angles to the first to shield the respective paper screens from the opposed lights which were placed one on either side of the centre shield at various distances from the screen, until the degree of illumination of the two pieces of tissue paper was equal, when the relative intensities of the light were calculated from their respective distances from the screen.

Foucault's method is practically the same, but the two pieces of tissue paper are replaced by glass coated with starch. Regnault used stearine in place of the starch. As will be seen later on, this is practically the same photometer as that now being used for testing the London coal-gas supply.

Huyghens used a tube with varying apertures, and observed the degree of illumination of the interior of the tube as an index. In 1792 Count Rumford employed a rod to throw a shadow upon a screen, and compared this shadow with a similar one thrown by the opposed light. Herschel employed the surfaces of white paper; whilst Ritchie, in 1826, noted the degree of illumination of two surfaces of white paper inclined to one another at an angle of 45°, a method which has been usefully adopted by various observers since. Wheatstone made use of a small bright ball rapidly rotating round a disc. The two sides of the ball were thus illuminated rapidly in succession, and formed a brilliant circle of light, the two sides of which were of equal brilliancy when the instrument was held in a position at which the two sources of light under comparison afforded equal illumination. In 1843 Bunsen introduced the now all but generally adopted grease spot photometer. In this instrument the disc of paper marked with the grease spot formed one side of a box in which was burning a small gas flame, which consequently illuminated one side of the disc. The reverse side being turned to the light under test, the distance was noted at which equal illumination of the two sides of the disc was obtained. The position of the box was then reversed, so as to face the light of comparison, and the observation repeated. The data thus obtained were then employed for calculating the value of one light in terms of the other.

This idea was elaborated and put into a more practical form by King, who arranged the greased paper disc on a travelling carriage carried on a graduated bar placed between the two lights to be compared. This was the forerunner of the photometers so generally employed at the present time for testing the horizontal rays emitted from gas burners, &c. The alternative to the grease spot of Bunsen is that of Leeson's star disc, which is composed of three pieces of paper, the centre one being stout paper perforated with an aperture in the form of a star. On either side of this is a piece of thin tissue paper unperforated. In its original form the arrangement was at times very faulty in consequence of the buckling of the papers, with the result that the shadow cast by the thick paper on one or both of the thin papers was more or less blurred and indistinct. This was remedied by the writer in 1880, by causing the three pieces of paper to adhere together by means of rice-water, when they were dried under pressure in order to obtain the disc perfectly flat. This treatment effectually prevented the separation of the papers, and caused the image of the star to be thrown into sharp relief. The improvement thus effected was so marked that the gas referees for the metropolis sanctioned the use of the disc for official testings. The great advantage of this form of disc over that of the greased paper is that by its means lights of different colour can be readily compared, as the combined action of the disc in casting a shadow of the thick piece of paper on the thin piece on either side respectively, combined with the comparison of the illuminated surfaces on either side by means of the opposing lights under test, affords all the advantages of the Rumford shadow method with that of the greased paper disc of Bunsen. It is true that for lights of equal colour the Bunsen disc is to be preferred in most cases, but for lights of totally different colour, such as that of a gas flame when used as a standard for measuring the intensity of the arc electric light, or the light of a Welsbach incandescent mantle, the advantage of the star disc is very great, so much so, in fact, that in certain cases it is impossible to obtain any reliable comparison without its use. Various other suggestions have been made from time to time, such as varying the angle of incidence of the rays on a given surface—photographic methods, polarisation, spectroscopic methods, &c. Draper, in 1843, employed as an index of the degree of luminous energy the extent to which the gases hydrogen and chlorine were caused to combine by the intensity of the light rays. An electrical method was employed by Becquerel in 1851, who measured the intensity of a light by means of the electrical current generated when two prepared silver plates were placed in water acidulated with sulphuric acid and connected, one of the plates being exposed to a stronger light than the other. Siemens and Halske proposed to utilise the fact that the electrical resistance of selenium is diminished by the action of light. Dr. H. Kruss, of Hamburg, described in 1888 an arrangement of prisms by Grosse, in which the method of polarisation was employed, and in which the mixing of light rays of different colours can be suitably arranged, or the intensity of the separated rays individually measured. Professor Joly proposed the use of two rectangular blocks of spermaceti placed side by side, so that each was respectively illuminated by one of the opposed lights.

As the use of the greased spot of Bunsen, or the improved star disc, is now all but universal, it will be well to devote a few detailed observations with regard to their use.

The Bunsen discs generally employed in England are made by compressing the piece of paper between two circular metal plates which hold it firmly in the centre. The whole is now revolved at a high speed, and whilst thus rotating the portion of the paper uncovered by the metal is plunged into a bath of spermaceti or wax dissolved in ether, or other suitable and easily evaporated liquid. On being removed from this bath and allowed to dry, the paper will be evenly coated on the outer portion with wax, and thus rendered translucent, leaving the centre portion opaque. In Germany the discs are made of thinner paper, having three rectangular grease patches in the centre.

When a new disc is first used it should be carefully tried to make sure that the indications on both sides are the same, as it not infrequently happens that different readings are obtained according to the side which is turned to one light or the other. If the indications are not precisely the same the disc should be rejected. With the view of facilitating this comparison, the author arranged the disc carrier on his radial photometer, hereafter to be described, in such a manner that it could be readily reversed simultaneously with the two mirrors which are employed for the purpose of enabling the observer to view the reflected images of the two sides of the disc at the same time. The proposal to mount the disc in a reversing frame was not new, having been employed by King and McMinn previously; but as the introduction of the mirrors by Letheby led to another source of error in consequence of the possibility of unequal reflection, it was necessary to guard against this as well as the errors of the disc itself. For this purpose it is now the practice to take two sets of observations, first with the disc and mirrors in the position in which they may happen to be at the commencement of the test, and to repeat these after the disc has been rotated on its axis, so as to reverse the position of the disc in regard to the lights under test. The mean of the two sets of observations is then taken to represent the true reading of the photometer.

In view of the fact that the disc is coated with a material particularly liable to collect floating particles of matter in the atmosphere, it is desirable that the disc should be carefully covered when the instrument is not in use, a precaution which was prescribed by the authorities having control of the gas-testing arrangements in the metropolis.

Standards of Comparison.—So far we have dealt only with that part of a photometer which enables the power of a given light to be compared with that of another which is employed as a standard. We have now to consider the various methods which have been suggested with the view of obtaining a reliable standard of definite value which shall be available under all conditions, and by means of which all artificial sources of illumination may be compared.

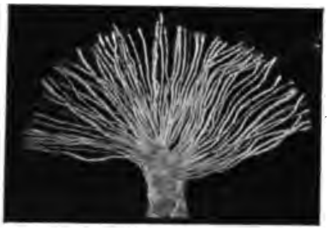
The commercial value which now pertains to definite degrees of illumination makes such a standard light a necessity, as by its means the value of all illuminants can alone be ascertained. All coal gas and electric supplies are, or should be, subject to control under legal restrictions, and it is obvious that in order to ascertain the quality of the supply, a simple and reliable source of light must be readily available for the comparison.

In 1760 Bouguer proposed the use of candles as a standard, but he did not define, so far as we are aware, the kind of candle to be employed.

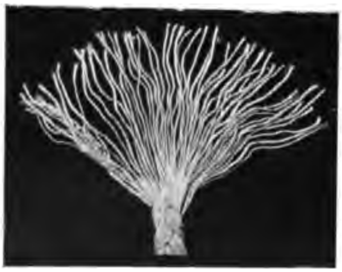
The suggestion, however, was not barren, as, although numerous substitutes have been proposed, candles used under defined conditions have been the only legal standard of light in England up to the present time. As will be seen later on, the writer's Pentane Argand, in a modified form, is now being introduced for legal testings of the illuminating power of the London gas supply by agreement with the Gas Companies, but outside the jurisdiction of the Metropolitan Gas Referees it has no legal force.

The parliamentary standard of light is the sperm candle, weighing six to the pound, each burning sperm at the rate of 120 grains per hour. It was first defined in the Metropolis Gas Act, 1860. As, however, it is almost impossible to obtain an exact rate of consumption equal to 120 grains of sperm per hour, the Gas Referees have specified that when the consumption falls short of 114 grains per hour, or rises above 126 grains per hour, the candles are to be rejected.

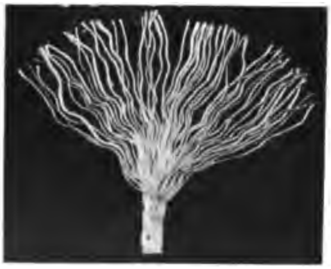
In actual work the rate of consumption is ascertained from observations of the time required to consume a definite weight of sperm, generally 40 grains, which should be consumed in ten minutes. If this time be less than 9½ minutes or more than 10½ minutes, the rate of consumption will be outside the Referees' limits, and the test must be repeated. The weight of a single candle should be 1167 grains nearly, but this varies in practice by about 20 grains. The length of the candle is about 8¼in., measured from the



Wick from 1870 candle. Light deviation from 1-candle Pentane flame + 5 per cent. Consumption of sperm, 121 grains per hour. Melting point of sperm, 110° F.



Wick from 1884 candle. Light deviation from 1-candle Pentane flame + 20 per cent. Consumption of sperm, 119 grains per hour. Melting point of sperm, 108° F.



Wick from 1892 candle. Light deviation from 1-candle Pentane flame + 16 per cent. Consumption of sperm, 108 grains per hour. Melting point of sperm, 104° F.

PLATE I.

To face page 27.]

shoulder. The diameter at the shoulder is about 8-tenths of an inch and that at the bottom 8½-tenths.

By the kindness of Messrs. Miller and Co., the well-known makers of most of the standard candles in England, the author is enabled to submit the following definition[*] of what they understood to be a "standard candle," according to the Act of 1860:—

"We think that there can be no doubt that at the time the Act was passed, a sperm candle was understood to consist exclusively of spermaceti (the product of the spermaceti whale), pure white, and dry, having a melting point of as nearly as possible 109° F., and to which was added just so much air-bleached beeswax, having a melting point of 140° F., as would suffice to break the crystals of the spermaceti; the rate of combustion, fixed at 120 grains an hour, being secured by a properly-proportioned cotton plait serving as the wick. With regard to the size of the candles to be used, we have never attempted to make candles which should individually weigh ⅙ lb., as we have understood the intention of the Act to be to indicate that the candles to be used should be those known in the trade as 'short sixes,' and which do approximately weigh six to the pound."

As illustrating the variations which have taken place in the character of the sperm candle, the accompanying Plate I. will be of interest. This shows the number and tightness of the plaiting of the threads in the respective wicks at different dates. The figures are reproduced from wicks obtained by the author from candles in his possession.

The method of using the standard candle is as follows:—

Select a candle from a packet of standard sperm candles, and see that it is straight, and the wick properly in the centre. Cut off the sloping top of the candle just at the shoulder, and then carefully divide the candle into two portions of equal length by cutting it through at the middle. The two ends which have just been formed by the cut must be trimmed by removing a portion of the sperm from the wick, which will be exposed. Thus (Fig. 2):

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[*] *Vide* 'Practical Photometry," by the Author.

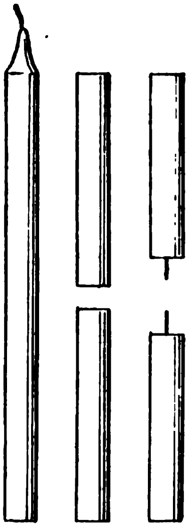

Fig. 2.

The two new wicks are then lighted, and the two candles mounted in a candle-holder suspended from a balance. When the candles have burnt for ten minutes they are to be turned round in such a manner that the plane of the curvature of one wick is to be perpendicular to the plane of the curvature of the other wick (Fig. 3). Thus:—

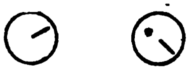

Fig. 3.

The object of this regulation is to ensure that the mean position of the two flames shall coincide with the terminal point of the photometer bar, whatever the position of the wicks may be. Objection had been raised to the practice of some photometrists in setting the candles in such a position that the edge of the flame was presented to the photometer instead of the side of the flame, with the result that, as pointed out by the writer in connection with his researches with the radial photometer, the volume of light emitted from the edge of the flame being less in proportion to that from the flat of the flame, the value of the standard candle light was vitiated, and the apparent value of the flame to be measured proportionately increased. The regulation referred to above was made on the suggestion of the late Mr. J. Methven, who gave the following reasons for it in a paper read by him before the Southern District Association of Gas Engineers and Managers on November 14th, 1889:—

***Experiments on the Value of the Light of Candle Flames.*—In making the following experiments, the light value of the flame of the**

candle was found to depend on the position its wick held with regard to the disc. It must be observed that candle flames, like flames from fish-tail burners, possess a flat side and an end, which, I think, drawing No. 4 will fairly represent. The centres of the flames

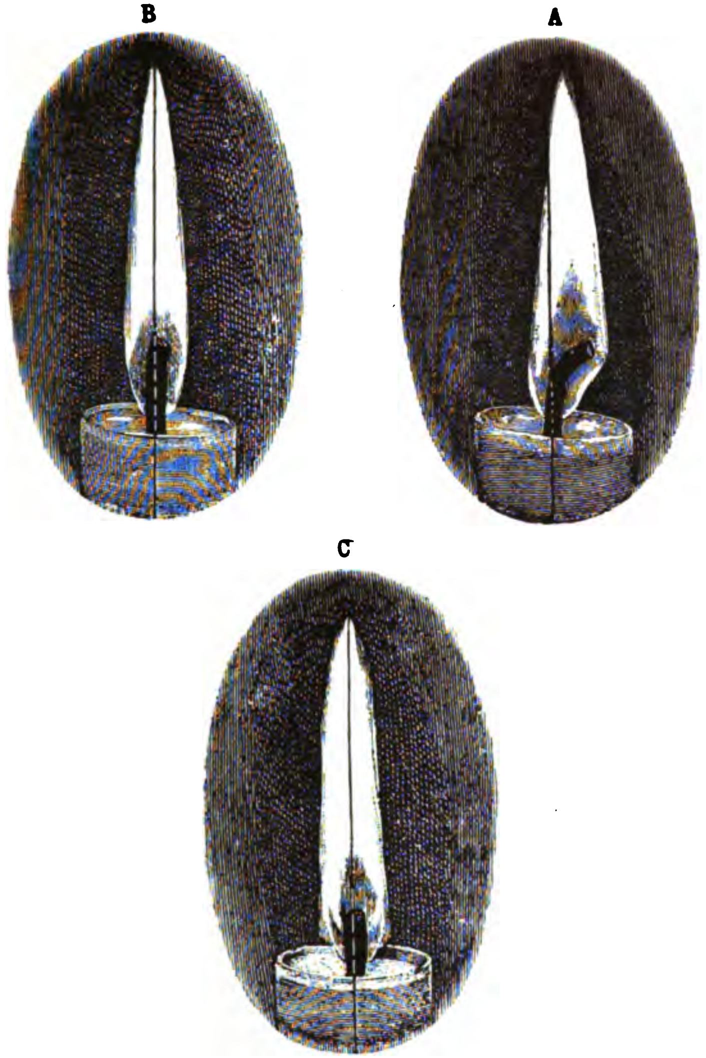

Fig. 4.

occupied one terminal of the photometer; and the candles were movable, so as to place their wicks in the required direction. A Methven screen and disc-box occupied the other terminal, provided with a supply of gas of constant quality; but as the screen value was rather greater than two standard candles, the mean lighting value of the candles appearing low must be attributed to this cause. The following figures are the mean results of a number of candles. Two distinct candles were used on each occasion:—

Position.	Light Value of Candle Flames in Standard Candles.
A. Plane of curvature of both wicks parallel to plane of disc	1·999
B. Plane of curvature of both wicks at right angles to plane of disc and bent away from disc	1·957
C. Plane of curvature of both wicks at right angles to plane of disc and bent towards the disc	1·933

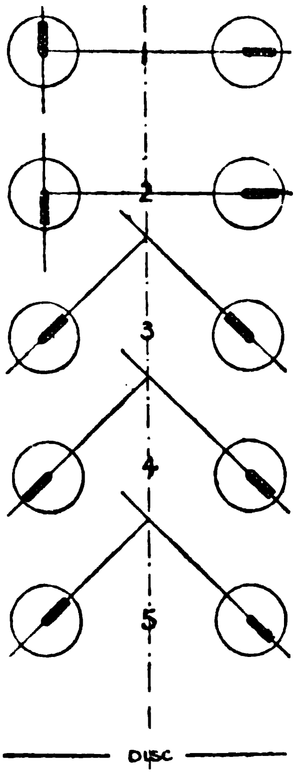

Fig. 5.

Diagram showing the various positions for placing the Wicks of Candles—all complying with the "Instructions" of the Gas Referees.

Taking the mean light value of the two candles from these results as 1·972 candles, the position A gives a result 1·37 per cent. above the mean; position B, 0·76 per cent. below the mean; whilst position C gives 1·97 per cent. below the mean. It is evident, therefore, that the position in which the wicks of the candles are placed (although the centres of their flames may, by means of an adjustable candle balance, occupy the terminal of the photometer) must cause a difference in the results of the testing. The Referees in their "Instructions" state that "the candles are to be so placed that the plane of the curvature of one wick shall be perpendicular to the plane of curvature of the other wick." There are several positions shown on Fig. 5, in which the wicks of the candles may be placed so as to comply with these "Instructions"; but there is only one position in which they can be placed so that their mean lighting value should be exposed to the disc, and that position is marked 5 on the diagram.

This alteration of position of the candle wicks is of great importance in the Evans photometer, where the index on the scale represents the centre of the candle. Fig. 6 represents graphically the error likely to arise from this cause. In the same manner, the value of the candle flame was determined, as above mentioned. The value of the light of the candle flame was observed when the centre of the candle occupied the position of the terminal of the photometer, corresponding to the manner in which it is used in the Evans photometer. With the wicks turned from the disc, the light value for 240 grains of sperm consumed by the candles was found to be 1·953 candles; with the wicks turned towards the disc, the light value was 2·032 candles. This amounts to a difference of 4 per cent.; and the returned results of the testing will, of course, vary to that extent against the gas when the wicks are facing the disc, and in favour of the gas when turned in the opposite direction. The difference on the diagram is represented as being 3·6 per cent.—a result fairly agreeing with the photometrical results. The "Instructions" of the Referees provide for nearly one-half of this possible error; but to make them complete the position shown in Fig. 5 (No. 5) should be adhered to. If candles were used in photometers in this position, the variations in photometrical results which have hitherto been ascribed to candles would to a great extent be removed.

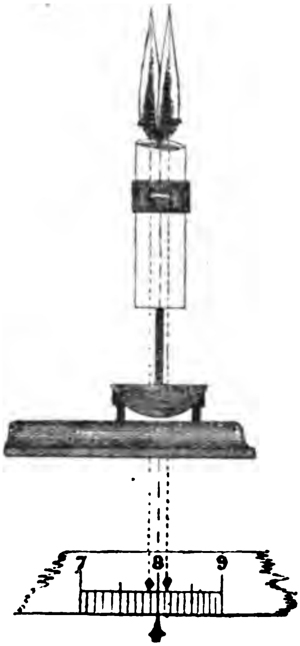

Fig. 6.—Photometers with Fixed Candle Holders.

Diagram showing the possible error due to the altered position of the candle wicks in the Evans Photometer. This error is increased on Photometers with shorter bars, and unprovided with adjustable candle balances.

The candles must be allowed to burn until the "cups are fairly dry," *i.e.*, free from melted sperm, the wicks properly curved and their ends glowing with a clean red heat.

In Schedule A, Part 2, of the Gasworks Clauses Act, 1871, it is stated that " the candles are to be lighted at least ten minutes before beginning each testing, so as to arrive at their normal rate of burning, which is shown when the wick is slightly bent, and the tip glowing."

The candles, suspended on the candle balance, are then counterpoised until their weight is a few grains heavier than the counterpoise. A stopwatch or clock must be at hand, by means of which the time observation is to be made. As the candles burn they become lighter; at the moment they become equal, or nearly so, to the counterpoise, the end of the beam of the balance to which they are suspended will rise. As the indicator of the balance passes the zero mark the stopwatch or clock is started and the test commences. A forty-grain weight is then carefully dropped into the pan provided for the purpose under the candles, when their end of the balance beam will again descend, thus bringing the candle holder to rest. The readings of the photometer are then taken at intervals of a minute during the succeeding 9½ minutes, at the expiration of which time the balance must be again carefully observed. As soon as a quantity of sperm equal to forty grains in weight has been consumed, the candle end of the balance will again rise, when, as the indicator again passes the zero mark, the clock is stopped, and the precise time, in minutes and seconds, which has been occupied by the burning of the forty grains of sperm noted.

The correction for the consumption of sperm is then made by a "rule-of-three" sum, thus, if forty grains of sperm were consumed in 10 min. 17 sec., we have :—

10 min. 17 sec. or 617 sec. $: 40 :: 600 : x = 38{\cdot}9$.

For convenience in practice a table is generally kept handy for reference. (*See Appendix.*)

It is assumed that the light intensity varies in the ratio of the sperm consumed, and the actual rate of consumption having been thus ascertained, the measured intensity of the opposed light under test must be corrected accordingly.

As two candles were employed in the operation, the result must be multiplied by two. Thus: the readings on the photometer bar being first multiplied by two, must then be corrected in the ratio of the sperm consumed by the candles, *i.e.*, if the sperm consumed was, as above, 38·9 grains in ten minutes instead of 40 grains, the candles were giving too little light, and the apparent value of the light under test would be too high, therefore it must be corrected in the ratio of

$$40 : 38{\cdot}9 : : \begin{array}{c}\text{observed}\\ \text{value.}\end{array} : \begin{array}{c}\text{corrected}\\ \text{value.}\end{array}$$

As will be seen later on, this tedious method is now being displaced by the more exact and simple method introduced by the author in connection with the Pentane Argand standard, by means of which all these corrections, &c., are done away with, and readings can be taken on the photometer bar direct, and require no correction so far as the standard of light is concerned.

The French standard is the Carcel lamp, in which refined colza oil is consumed at the rate of 42 grammes per hour. This was introduced in 1800, and is the legal standard in that country at the present time, having held its own against all competitors. The value of this standard is equal to 9·5 of our parliamentary standard sperm candles. The wick of the Carcel lamp, so named after its inventor, is annular, as first devised by Argand. The oil is forced up from the reservoir in the body of the lamp by means of a small pump actuated by clockwork. The following instructions for its use are those of M. Monnier, who gives them in his "Etude sur les Etalons Photométriques":—

"The conditions to be observed when testing with the Carcel lamp are by no means definite, as each lamp must first be tested before being used as a photometric standard. The rule, however, is that the height of the wick and chimney must first be arranged so that the consumption of the oil is within the range of 38 and 46 grammes of oil per hour; but for exact experiments it is preferable to restrict these limits, and maintain the consumption between 40 and 44 grammes per hour. The light given by the lamp is corrected on the assumption that 42 grammes of oil per hour equals one 'Carcel.'"

Experiments by MM. Audouin and Bérard show, firstly, that an increase in the height of the wick up to 10 mm. augments the consumption of the oil as well as the intensity of the light; and that beyond that point both the consumption of oil and the intensity of the light diminish. Secondly, that the elevation of the constricted portion of the chimney tends to augment the consumption of the oil in increasing ratio; but that there is a point where, although the consumption continues to increase, the intensity diminishes. Consequently, there is a height of the glass chimney which corresponds to the maximum illuminating power of the lamp.

For each experiment a new wick is necessary, which must be cut level with the wick holder. The lamp, replenished with oil up to the level of the gallery, must be allowed to burn for half an hour before commencing the experiment.

The height of the wick must be from 8 mm. to 10 mm., and the shoulder of the glass about 7 mm. above the wick, and that of the flame about 36 mm. The calculations for correction of the light from the observed consumption of oil are facilitated by the use of a table given in the appendix.

In 1808 Murdoch used a standard tallow candle weighing six to the pound, and burning at the rate of 175 grains per hour.

In 1824 Ritchie introduced wax candles.

In 1863 Zincken suggested paraffin candles, which he burnt at the rate of 115·2 grains per hour. These are now employed as the German standard, having been adopted by the German Association of the Gas and Water Profession in 1872, when they were defined as follows:—"The paraffin candles made for the Association under the supervision of a Special Committee, are issued by the manager at cost price. Ten candles weigh 500 grammes. Each candle has a true cylindrical form and a diameter of 20 mm., and is made of the purest possible paraffin, with an addition of 2 per cent. of stearine. The point of solidification is 55° C. The wick is plaited of 24 cotton threads, as uniformly as possible. One metre of wick, in a dry condition, weighs 0·688 grammes. A red thread in the wick distinguishes the Association candle from others.

The flame of the candle when used for photometric tests should have a height of 50 mm., measured from the commencement of the flame at the wick to the point. To obtain this height the lighted candle should be allowed to burn quietly until an even cup of liquid paraffin is formed. By carefully snuffing the wick, if necessary, the flame is to be brought to the height of 50 mm., and maintained thereat. In this condition the consumption of paraffin amounts to 7·7 grammes per hour.

The most suitable temperature of the room in which the photometric measurements are made is that of 14° Reaumur = (17·5° C.) = 63·5° F.

In 1865 Fiddes proposed the use of an Argand gas flame surrounded by an opaque chimney having an aperture of ¼in. in diameter at about the middle of the flame.

In 1868 Crookes constructed a lamp fitted with a platinum wick, with which he burnt a mixture of alcohol and benzol.

In 1867 Bowditch proposed the use of a carbonic oxide flame rendered luminous by the vapour of pure naphthalene.

In 1869 Keates proposed his original pattern of a moderator lamp burning sperm oil. This was adjusted to a value of ten candles, but was afterwards modified by Sugg so as to give a light equal to sixteen candles when burning the oil at the rate of 925 grains per hour.

In 1874 Von Wartha suggested a flame obtained by the burning of ether.

In 1877 A. G. Vernon Harcourt devised the 1-candle pentane lamp, in which a mixture of air and the vapour of pentane was consumed at a given rate. The following description is taken from Mr. Harcourt's paper, read before the Physical and Chemical Sections of the British Association at Plymouth in 1877:—

> For the standard combustible, I employ a mixture of air with that portion of American petroleum which, after repeated rectification, distils at a temperature not exceeding 50° C. This liquid consists almost entirely of pentane, the fifth member of the series of paraffins. I have made three or four analyses of the liquid, which, though they scarcely distinguish between pentane and the adjoining hydro-carbons of the same series—the proportion of carbon to hydrogen being in pentane, carbon 83·3, hydrogen 16·7; and in hexane, carbon 83·7, hydrogen 16·3—would reveal the presence of small quantities of hydro-carbons richer in carbon. I have also determined the vapour density of the liquid. The density of gaseous pentane compared with hydrogen is 36; that of hexane 43. I find the vapour density of the liquid, distilled twice below 50° C., to be 37. The lighter portions of purified American petroleums have been carefully examined by Ronalds, Cahours, Warren, Schorlemmer, and other chemists, and have been found to consist of the following hydro-carbons:—Tetrane, boiling between 4 and 0, and having a specific gravity of 0·6° at 0° C.; two isomeric pentanes, one boiling at 30° and the other at 37°, and having at 17° a specific gravity of 0·626 (Schorlemmer), 0·628 (Cahours), the proportion of which appears to vary, since the hydro-carbon separated by Cahours boiled at 30°, while Schorlemmer states that the pentane in the samples examined by him consisted almost wholly of the variety boiling between 37° and 39°; hexane, which boils at 68° C., and has a specific gravity at 16° C., of 0·669. The liquid I use has a specific gravity which has only varied in different samples between 0·6298 and 0·63, except in one case, in which, probably owing to the temperature of distillation having been allowed to rise too high, it was 0·631. It would not be difficult by rectifying at 40° to obtain almost absolutely pure pentane. But I do not think it necessary to limit the distillation to this temperature, because the yield at 50° is rather larger, and it seems hardly possible that the admixture of a small and nearly constant proportion of a substance so little different as hexane can affect the quality of the liquid as a combustible. Also I find, having distilled ten or twelve samples of the liquid, using about three litres each time, that I get a constant specific gravity.*

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* Letter from Mr. Vernon Harcourt to the Board of Trade Committee on Photometric Standards in 1881.

Air-gas is prepared from this pentane in the following manner:—

"By allowing a measured volume of this liquid to diffuse into and mix with a measured volume of air in the proportion of three cubic inches of the liquid to every cubic foot of air under an atmospheric pressure of 30in. of mercury, and at the temperature of 60° F., a standard air-gas may be prepared in any required quantity.

"A small gasholder is employed for the mixture of the pentane and air. When three cubic feet of air and nine cubic inches of light petroleum are used, the total volume of standard air-gas formed is 4·05 cubic feet. The observation of this volume serves as a check on the preparation of the standard air-gas. Allowing a margin of 1 per cent. each way for small errors in measuring and making the gas, and for variations in the vapour density of the rectified petroleum, I would propose, in defining the standard air-gas, to require that the volume produced from three cubic feet of air and nine cubic inches of petroleum (specific gravity 0·628—0·631) shall not be less than 4·01 nor more that 4·09 cubic feet. The gas thus prepared is subjected to a further control by the requirement that its rate of burning from a ¼in. orifice to produce a 2½in. flame must not be less than 0·48 nor more than 0·52 cubic foot per hour."

This suggestion of Mr. Harcourt's was recommended for adoption as the legal standard by the Board of Trade Committee on Photometric Standards in 1881, by the Controlling Authority under the Acts relating to the testing of the gas in the metropolis, and by the Standards of Light Committee of the British Association; but the Board of Trade Committtce, appointed in 1891, to inquire into and report upon the subject of the standards to be used for testing the illuminating power of coal gas, did not adopt that view, as will be seen later on.

In 1878 Methven proposed his slotted screen. This was a modification of Fiddes' Aperture, which Methven now made rectangular instead of circular. In the original form of the appliance he used plain coal gas; but subsequently he enriched the gas with the vapour of pentane, and reduced the size of the slot through which the light passed to the photometer disc. In both these forms the proposal met with much favour. Shortly afterwards Sugg put forward an instrument which had for some time previous been in daily use in his business for testing the illuminating power of burners, viz., the "ten-candle test." In this arrangement the top of a small Argand flame is cut off by a screen in the manner described by the writer in the course of a discussion at the Society of Arts in 1882, as having been employed by him for the purpose of obtaining a steady light when standardising the "Keats lamp." The light from the bulk of the flame is employed, including the "blue," or lower portion, whereas Methven and Fiddes employed only a small portion of the brightest part of the centre of the flame.

In July, 1884, the writer was instructed by the Special Purposes and Sanitary Committee of the late Metropolitan Board of Works to carry out a systematic series of tests with the view of ascertaining the most suitable substitute for the standard sperm candle. In the course of these investigations he found that by modifying the construction of the "ten-candle test" so as to enable it to burn a mixture of pentane and air, a far more reliable standard was obtainable than by any one of the other systems proposed. The necessary alterations were therefore made by Mr. Sugg, and the burner was mounted on a carburetter, such as that used by Methven for carburetting the coal gas supplied to his modified form of slot as mentioned above, but instead of gas being supplied to the burner, atmospheric air was sent directly over the pentane in the carburetter, with the result that an air-gas was produced, which, when burnt in the burner at a definite height of flame, gave a standard far surpassing all others both in accuracy and ease of manipulation (Fig. 7).

This proposal was accordingly examined by the Board of Trade Committee appointed in December, 1891, who reported in March, 1895, as follows:—

"(5) We find that the one-candle light flame, as proposed by Mr. Harcourt as giving a standard light, and commonly known as the 'Harcourt pentane air-gas flame,' when used under the conditions defined, does constitute a very exact standard, capable of being reproduced at any time without variation of illuminative value."

"(6) We have satisfied ourselves that the light given by Mr. Harcourt's above-mentioned pentane air-gas flame, as defined in respect to the conditions of its production in the Appendix (Section 111), is a true representative of the average light furnished by the sperm candle flame constituting the present standard. Since 1879, when the pentane air-gas flame was first introduced, many series of experiments have been made by different observers, in which the light of the proposed standard has been compared with the light of the standard sperm-candle flame, with the result that in those series of experiments in which the height of the pentane air-gas flame was adjusted strictly according to the directions given in the Appendix, the light afforded by this flame was found to agree exactly with the mean result afforded by the standard flame. In other series of experiments, indeed, in which a slight variation was made in the mode of adjusting the height of the pentane air-gas flame, some discrepancies in the direct results furnished by the comparison of its light with that of the standard candle flame were observed; but in these several series of experiments also, when the necessary correction called for by the difference in the mode of adjustment resorted to was made, the light of the pentane air-gas flame was found to accord closely with the mean result afforded by the standard flame."

"(7) Inasmuch, however, as there is a practical advantage in comparing directly the light of such a coal-gas flame as is usually tested—being, that is, of about a 16-candle light value—with a light approximating somewhat in value thereto, we have further submitted to careful examination the flame of the 10-candle light pentane Argand proposed as a standard by Mr. W. J. Dibdin in 1886. This flame is produced by burning a mixture of air and pentane vapour from a suitable Argand burner, provided with an opaque screen, by which the light from the upper portion of the flame is cut off. The screen being set at a definite height, it was found by Mr. Dibdin that, owing to a compensating action affecting the lower or exposed portion of the flame, the luminosity of this portion of the flame remains constant even under considerable variations, whether in the total height of the flame or in the proportion of the pentane vapour to air in the mixture burnt. With a view to simplify the construction of the Argand burner furnishing a cut-off flame of this constant luminosity, we have tried various changes in the form of the cone and in the division of the air supply to the flame, but in every case we have found the original burner, as supplied by Mr. Sugg for the purpose, to give more satisfactory results than the modified forms."

"(8) The amount of light emitted by the portion of the Dibdin Argand pentane-air flame that is used in photometry, being dependent on the distance above the steatite ring of a screen by which the upper part of a flame is cut off, we have come to the conclusion that when the bottom of the screen is fixed at a height of 2·15in. (54·6 mm.) above the top of the steatite ring, the amount of light emitted by the lower portion of the flame is substantially equal to ten times the average light of a standard sperm candle flame, or to ten times the light of Mr. Harcourt's one-candle light pentane-air gas flame."

"(9) We have further satisfied ourselves that any number of Dibdin Argand burners may be produced, having the form and dimensions set forth in the Appendix (Section IX.), and that these several burners, when used in the manner there defined, may be depended upon to furnish a flame giving, when duly screened at the top, ten times the average amount of light given by an average sperm candle."

"(10) We therefore recommend that the pentane-air flame furnished by a Dibdin Argand burner, having the form and dimensions set forth in the Appendix (Section IX.), and used in the manner there defined, be accepted as giving the light of ten standard candles, and that this flame be authorised and prescribed for official use in testing the illuminating power of the gas supplied by the London gas companies."

"(11) We further recommend that sealed specimens of the burner, the carburetter, and the pentane for use therewith, duly certified by the Gas Referees, be deposited with the Board of Trade, and also in such places and in the care of such persons as the Board of Trade may direct, to be available for the purpose of comparison, in the event of any question arising as to whether the pentane-air flame of some particular burner does or does not afford the same amount of light as that now proposed for adoption as a standard."

"(12) With a view to making some provision for future possible improvements and requirements, we further recommend that the Gas Referees be authorised, should they at any time see fit, to approve and certify for use in gas testing any other flame based upon the 10-candle standard defined above, which they may consider suitable for the purpose, whether produced in a like or unlike way, and whether having the same or a different multiple value; such other flame, however, not to be used for gas-testing unless approved by the Board of Trade, and unless the gas companies give their consent to its adoption as a standard."

After some four years' debate on this report, the recommendations of the Committee are now being carried into effect. The form of chimney used with the burner as tried by the Committee has been replaced with an elongated metal one, having an opening towards the photometer disc, with the view of removing one of the objections that had been raised to the glass chimney which, if not perfectly true all round, would be liable to materially affect the intensity of the light emitted in the direction of

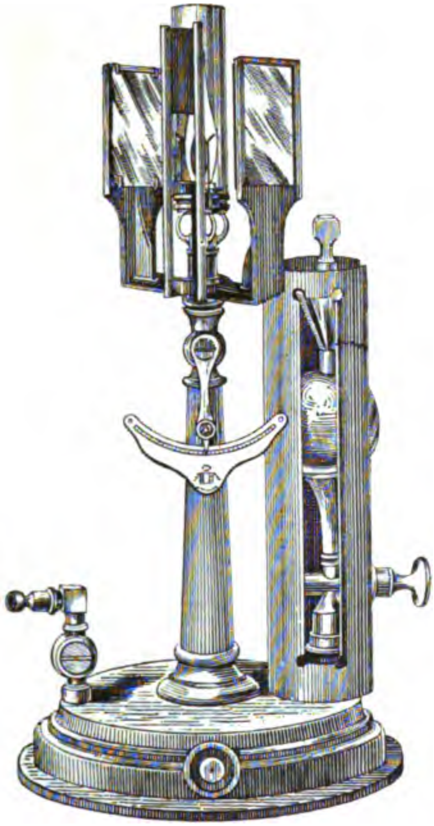

Fig. 7.—W. J. Dibdin's Pentane Argand and Carburetter.

the photometer. By allowing the rays to pass direct without the interposition of glass this danger is avoided. Another alteration has been made, in that instead of the current of air passing over the pentane contained in the reservoir or carburetter, the latter is now raised to a point

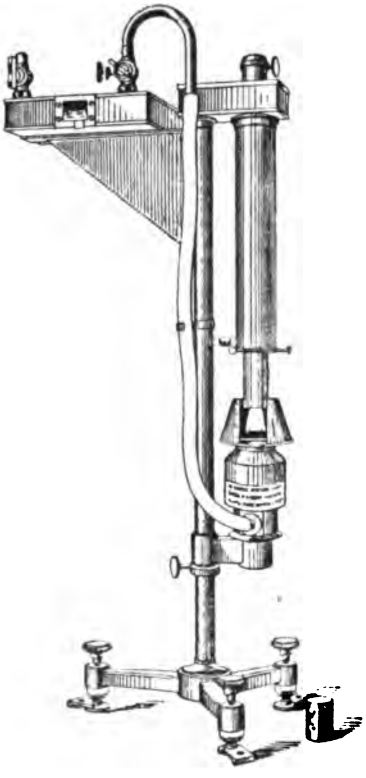

Fig. 8.—Harcourt's 10-Candle Pentane Lamp.

above the level of the burner, from whence it is found that the mixture of air and pentane automatically flows downwards by the action of gravity to the burner, thus doing away with the necessity for the use of a small gasholder to contain and force the air under pressure to the carburetter (Fig. 8). The essential feature, as designed by the writer, however, remains, viz.:—That the intensity of the light is to a great extent controlled by the use of the screen, which cuts off the rays from the top portion of the flame, this being the principle of the system, which permits of the remarkable self-compensating action enabling the arrangement of burner and screen to afford a constant light under considerable differences of temperature, height of flame, and variation in the composition of the combustible gas with which it is fed.

The arrangement, as recommended by the Board of Trade Committee, is fully described in the appendix to their report. The accompanying illustrations of the author's design of the Pentane Argand (Fig. 7) and the modification designed by Harcourt (Fig. 8) will serve to show the nature of the system and the alterations since made therein.

In 1884 Herr Von Hefner-Alteneck proposed the amyl-acetate lamp, which has met with much approval, especially in Germany. It is a simple form of spirit lamp, giving a flame of 40 millimetres in height, caused by the combustion of amyl-acetate, better known in commerce under the name of "pear oil." The illuminating power of the flame is said to be equal to one standard candle; but in the course of his researches the writer has found it necessary to raise the height of the flame to 51 millimetres, or 2in., to obtain the light of an average sperm candle. The objection to this standard by English photometrists is based on the red colour of the flame, which renders equal readings of the disc by different operators a matter of uncertainty.

In 1843 Draper proposed to use platinum wire raised to incandescence by a current of electricity.

In 1880 Violle employed the light emitted from a cubic centimetre of platinum at the moment of its greatest brilliancy—when just beginning to solidify after being in a molten state. This system was at one time recommended by a congress of electricians which met in Paris, but a similar congress subsequently rejected it, recommending the adherence to the Carcel lamp.

Numerous other proposals have been made from time to time, but they are all more or less modifications of the foregoing, or have nothing sufficiently characteristic or promising about them to warrant their more particular notice. For instance, the Dutch Photometric Commission, after a laborious examination of the different proposals, came to the conclusion that a lamp of practically identical pattern with that adopted by Harcourt for a portable form of his one-candle standard was the best, but instead of burning pentane in it they used a mixture of ether and benzol, and called the arrangement the "A B" lamp. As mentioned above, Crookes, in 1868, proposed a mixture of alcohol and benzol.

CHAPTER II.

PHOTOMETERS.

HAVING now discussed the two essential parts of the photometer, viz., the disc, as it is commonly termed, or actual means of comparison, and the standard of light with which the light under test is to be compared, it will now be advisable to describe the different forms of instruments in which these two essentials are mounted for their more convenient use.

The complete instrument known as a "photometer," or light-measurer, comprises several parts, viz., first, the disc, or that portion of it by means of which the light under test is to be compared with the standard light; secondly, the standard light itself; and thirdly, the scale by means of which the readings are taken. We have already discussed the two first essentials, and have now to consider the third. This, however, assumes such varied forms that it is impossible to describe it without more fully considering the different forms of instruments which in their entirety constitute a "photometer."

Most of the instruments of this kind are intended solely for the purpose of testing the rays emitted from a radiant in a horizontal direction, but the necessities of modern improvements have rendered this comparatively simple system all but useless for many purposes, and it was in order to place in the hands of the photometrical expert a thoroughly reliable and convenient instrument that the writer devised the radial photometer, by means of which the intensity of the light emitted in any direction can be readily and accurately measured.

Before describing this instrument it will be advisable to refer to those intended for testing horizontal rays only;

then to the radial photometer and others founded upon it; and, finally, to such instruments as those of Sugg and Trotter, for measuring the degree of illumination upon pavements, &c., *in situ.*

King's Photometer.—This instrument was an adaptation of Bunsen's photometer for testing the illuminating power of coal gas. It consisted of a wooden bar, 100in. in length, mounted on supports. The bar was graduated to indicate the relative intensities of two lights, one at either end of the bar, so that when the Bunsen screen, which was mounted on a travelling carriage, showed equal illumination on its surfaces when placed at any point on the bar, the intensity of the greater light was indicated on the scale in terms of the lesser light. Thus, if the screen showed equal intensities at a point equidistant between the two lights, viz., at the centre of the bar, the graduation corresponding to the position of the screen indicated "1," but if the position of the screen was towards the right-hand radiant the scale indicated that the left-hand radiant was greater in intensity than that on the right hand, &c. This instrument was used in a darkened room, the walls and ceiling being preferably blackened to avoid reflected light interfering with the indications of the screen. The bar and screen were kept as free as possible from all unnecessary accessories.

Letheby shortened the bar of King's photometer to 60in. between the lights, and improved the indications by using two candles during each of the testings, instead of only one, as used by King, with the object that the inequalities of one candle might be counterbalanced by those of the other. He facilitated the reading of the two sides of the Bunsen disc by fitting it in a "sighting box," in which he arranged two small mirrors, so that the observer could simultaneously see the two reflected images of the screen, one on each side. As the direct rays from the candles and gas respectively shining into the eyes of the observer interfered with the delicacy of the readings, screens were provided to cut these off. In order to modify the effect of draught on the gas-burner and candles, these were surrounded with large boxes open at the top and partially so at one side. The disc was either Bunsen's or Leeson's, as the observer might prefer. The instrument was used in a darkened room.

The Canadian pattern of photometer was arranged by Messrs. Sugg and Co., to enable the Letheby pattern to comply with the requirements of the Standard Department of the Board of Trade when certifying a photometer for the Canadian Government. In this modification the whole of the gas-measuring apparatus, viz., meter, governor, &c., as well as the photometer itself, is enclosed in a small wooden room shut in with heavy curtains to exclude extraneous light.

The Improved Letheby or "Tooley-street" Pattern is a modification of Letheby's suggestion, and contains improvements proposed by the writer which undoubtedly contribute to the accuracy of the results. During his investigations on the standards of light, the writer found that the draught caused by convection currents in the form of boxes then in use, caused the candle and gas flames to sway about and thus to give variable results. In order to overcome this it was found that if the chamber or box was covered with a perforated screen so as to leave an opening 6in. in diameter immediately over the flame for the vitiated air to escape, and the sides closed all round except for three or four inches at the bottom, the flames immediately become perfectly steady, and much more concordant readings were obtainable. It will be seen that the convection currents were avoided, and in their place there was obtained a steady flow of a large volume of air free from side or top draughts.

The second improvement consisted in fitting the writer's arrangement of reversing disc and mirror holder. Other improvements of a minor character were made, and in its new form the instrument came into much favour.

The closed Evans photometer was first introduced by the late Mr. F. J. Evans, engineer to the Gas Light and Coke Company, in 1858, in consequence of a dispute with the St. James's Vestry as to the illuminating power of the street lamps. After much discussion it was decided to test the gas burners *in situ,* as the Local Authorities would not consent to the removal of the burners to a proper testing-room. An instrument was therefore designed by Mr. Evans, and mounted on a platform in Piccadilly. It consisted of an oblong box, over the two ends of which were placed metal ventilating chimneys to allow the escape of the products of combustion of the gas and candles respectively. The end in which the gas burner was to be placed was of such a size that it could be placed bodily over the street lamp. The disc was permanently fixed in the box at a point 50in. from the gas flame, the candles being mounted on a travelling carriage, so that the readings of the instrument were taken by moving the candles instead of the disc, as in King's photometer. The movement of the candle carriage was regulated by a winch handle immediately in front of the observer as he stood watching the disc, an endless cord connecting the winch with the candle carriage. Doors were fitted to the box for giving access to the burner, disc, and candles respectively.

When Mr. Evans was appointed one of the Gas Referees in 1868, this instrument was adapted for official use in the gas-testing stations. Its indications, however, have been so variable that it is no longer sanctioned by that authority. The reader will find the question of its reliability fully discussed in the writer's work on "Practical Photometry, page 34, *et seq.*

The Imperial Photometer is a modification of the Evans, and was constructed by Messrs. Sugg and Co. to overcome the objection to the fixed disc and moving candles. It is, in fact, a combination of the Tooley-street pattern above referred to, with that of the Evans. Careful experiments by the writer have shown that this instrument gives most excellent results. Of all closed photometers it is undoubtedly the best. The gas to be tested for its illuminating power, and the candles or other standard employed, are burnt each in one of two square "towers" or chambers, which are about 2ft. square.

To ensure a large volume of air, moving at a slow speed, being supplied to the respective radiants in a manner ensuring full combustion, but not so fast as to disturb the steadiness of the flames, it is admitted into the base of the "tower" through a plate of perforated zinc, and after passing the points of combustion emerges from the chimneys at the top of the two towers. By this arrangement both the gas and candle flames are kept perfectly steady. The two towers are separated from one another by the length of the graduated photometer bar, usually 60in. in length, but this can be altered by the makers as desired. Careful provision is made for setting the candles and gas flame at points exactly corresponding to the terminals of the scale, plumb lines being provided for this purpose. The disc carrier is provided with the rotating movement mentioned in connection with the Tooley-street pattern, and in other respects the instrument is made as perfect as possible.

Harcourt's Table Photometer.—This instrument is now being prescribed by the London Gas Referees (of whom Mr. Harcourt is a member) for use in the metropolitan gas-testing stations. The following description is taken from the instructions of that body issued by them to the Official Gas Examiners (Fig. 9):—

The several parts of the apparatus stand upon a well-made and firm table, 5ft. 6in. by 3ft. 6in., and 2ft. 5in. high. The upper surface of this table is smooth, level, and dead black. Upon this are placed or clamped in the positions shown in Fig. 9:—(1) The gas meter. (2) The gas governor. (3) The regulating tap. (4) The "Sugg's London Argand No. 1" burner. (5) The connecting pipes. (6) The pentane 10-candle lamp. (7) The photoped. (8)

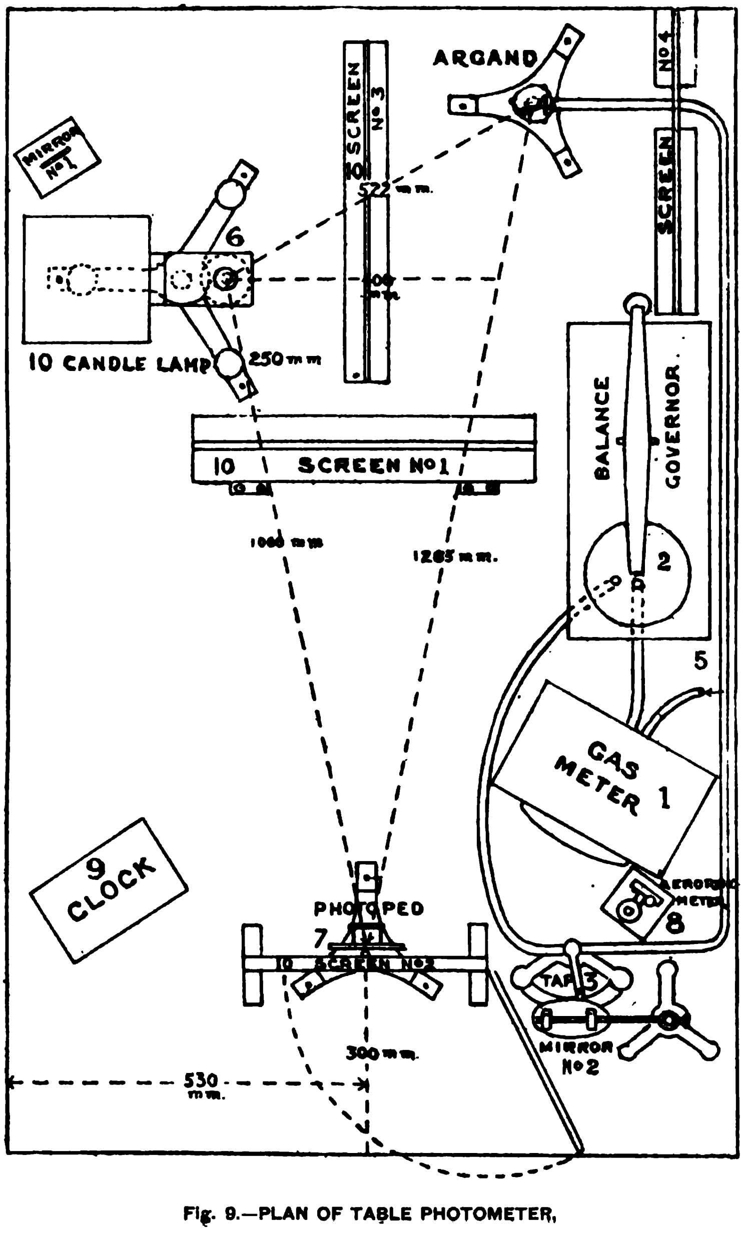

Fig. 9.—PLAN OF TABLE PHOTOMETER.

The aërorthometer. (9) The stop clock. (10) Dark screens; mirrors.

(1) *The Gas Meter.*—The gas meter is sufficiently described elsewhere.

(2) *The Gas Governor.*—The gas governor must be such as will effectually do away with any variation of pressure produced by the working of the meter or other causes.

(3) *The Regulating Tap* (Fig. 10).—This must have a large well-fitting barrel with a round hole on each side of such a size as to allow gas to pass at the rate of about four cubic feet per hour under the pressure at the outlet of the governor. In addition there must be narrow saw-cuts on opposite sides of the two holes when viewed in plan, which will allow an additional passage of about two cubic feet of gas per hour when the tap is so turned that the holes and the saw-cuts are both opposite the orifices of the fixed part of the tap.

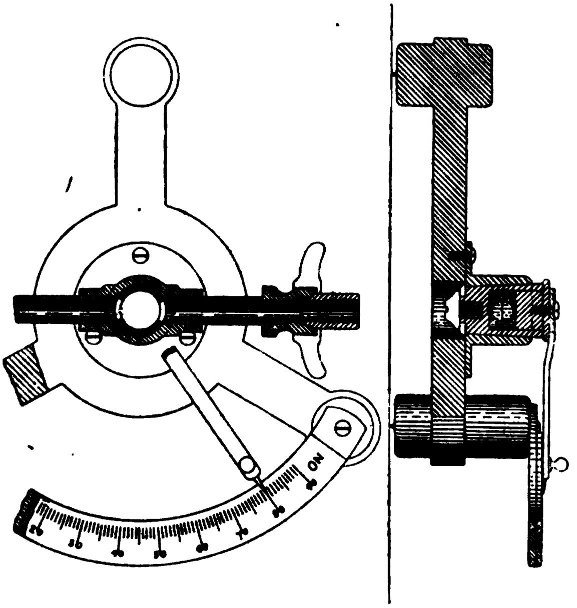

Fig. 10'

The construction of the tap is shown in Fig. 10. The index must be secured to the barrel without any play, and its pointed end must pass over a scale graduated in degrees upon an arc of not less than 80 mm. radius. The arc is to extend over 90 deg., and the degrees are to be numbered from 0 deg. to 90 deg. The arc is to be made of white enamel glass, and the divisions are to be etched upon it, and the marks filled in with black. The tap is to be off when the pointer is at one extremity of the arc at 0 deg., and fully on when it is at the other extremity at 90 deg. The small hole should be fully open at about 20 deg., so that the action of the saw-cuts may extend over the remaining portion of the arc. The tap must be kept clean and sufficiently lubricated to work easily.

(4) *The "Sugg's London Argand No. 1" Burner.*—This is the burner described in Appendix D. It is to be mounted upon a tripod with flat projecting feet, so that its position upon the table can be adjusted at any time. It may be clamped in position by three ┌ shaped clamps, each made to pinch upon one foot by the action of a single carpenter's screw. The construction of the foot and clamp is shown in Fig. 11. The height of the top of the steatite burner is 353 mm. above the table. The axis of the burner should be vertical. If it is found to lean in any direction, paper or card should be inserted under one or more of the feet until it is found to be vertical after being clamped in position.

(5) *The Connecting Pipes.*—These are to be made of ½in. (outside measure) composition piping. They are to be connected with the different pieces of apparatus by ⅜in. unions, except in the case of the gas meters, where the unions belonging to the meter may be retained. In all cases the boss of the union is to be attached to the apparatus and the cap and lining to the ends of the connecting pipe. These pipes are to be placed above the table. No grooves, recesses, or holes, other than the screw holes for the screws referred to in this Appendix, are to be made in the table.

(6) *The Pentane 10-Candle Lamp.*—This has been de-

scribed in a previous article. The lamp need only be placed in position upon the table, but for permanent use clamps corresponding to those used to secure the feet of the London Argand stand should be employed. The height of the top of the steatite burner is 353 mm. above the table. The construction of the screw, swivel plate, and clamp, is shown in Fig. 11.

(7) *The Photoped.*—The photoped is represented in Fig. 12; it consists of the following parts: a plate, 100 mm. square, with a central hole 21 mm. square. This is held in a vertical position by an upright support, so that the centre of the square is 400 mm. above the table. The upright is carried by a tripod similar to that used for the London Argand, and secured in the same way to the table. To one face of the square plate is fastened, by two binding screws, a clamping plate, 60 mm. by 40 mm., also with a central hole, 21 mm. square, so that the two openings are opposite one another. A piece of suitable white paper is pinched between the two plates so as to cover the openings and project a little way below the clamping plate. The clamping plate carries centrally a horizontal tube about 35 mm. in diameter and 30 mm. in length. In this slides smoothly a smaller tube containing a diaphragm in which a rectangular slit, 25 mm. by 7 mm., has been cut. To the upper surface of the larger brass plate, and on the same side as the clamping plate, is fixed a strip of glass, so that the lower edge is close to, and exactly

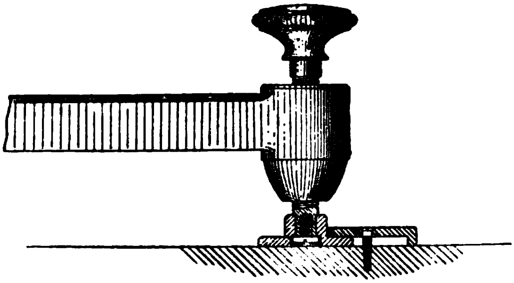

Fig. 11.

parallel to the plate, while the upper edge is so much in advance as will allow the reflection of the flame described elsewhere to be observed. The photoped should be plumbed vertical. If it is found to lean sensibly towards or away from the lamps, paper or card should be inserted under one or more of the feet until it is found to be vertical after being clamped in position.

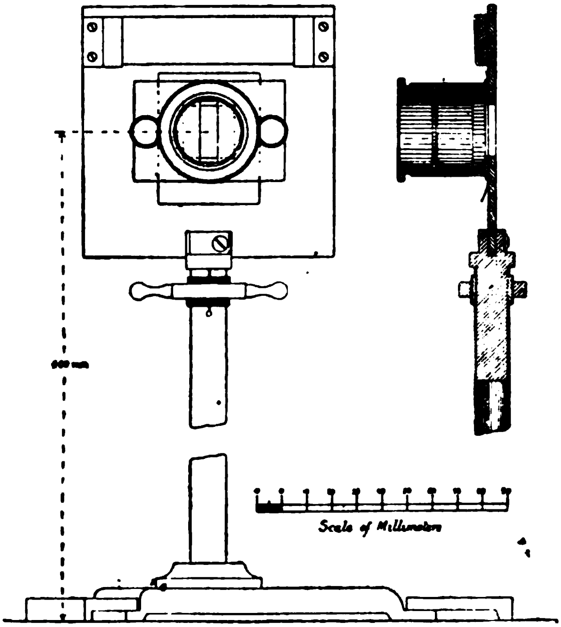

Fig. 12.

(8) *The Aërorthometer.*—This is in effect an air thermometer and a barometer combined, consisting of a bulb and vertical stem in which sufficient water is present to ensure that the air is saturated. The measuring tube, which terminates in a closed bulb, and a companion tube which is open to the air, dip into a reservoir of mercury in the base, the capacity of which can be adjusted by a regulating screw pressing on a leather cover. The relative volume of

the bulb and tube down to any division is represented by the number belonging to that division. In using the aërorthometer, turn the screw up until the level of the mercury in the open tube is below that of the mercury in the bulb tube; then turn the screw slowly down until the mercury stands at the same level in both tubes. The division at which the mercury now stands is the aërorthometer reading. The gas examiner shall, not less often than once a month, compare the aërorthometer reading with the reciprocal of the tabular number deduced from observations of the barometer and thermometer, and if there is a difference of more than one-half per cent. the instruments are to be readjusted.

(9) *The Stop-clock.*—This is the clock ordinarily used in testing places, either attached to the meter or independent of it. It must be provided with mechanism for starting and stopping. It will facilitate the comparison with the standard clock if it is made to give an audible sound, by means of a bell or otherwise, at the completion of each minute.

(10) *Dark Screens, Mirrors.*—Five dark screens are provided in order to prevent the inaccuracy and inconvenience to which stray light would give rise. The first is placed between the burners and the photoped in the position shown in Fig. 9. This screen is 500 mm. square, with two rectangular openings. The opening to the left is 40 mm. wide and 55 mm. high, and its lower edge is 350 mm. above the table. The opening to the right is 50 mm. wide, its lower edge is 340 mm. above the table, and it extends to the top of the screen. The centre lines of these two openings are 300 mm. apart. The screen is carried by a wooden foot about 500 mm. by 100 mm. and 30 mm. thick. Care must be taken that it is so adjusted that the whole of the flame under the tube C of the 10-candle lamps, and the whole of the chimney and burner of the Argand can be seen through all parts of the slit of the photoped when the paper is removed for that purpose. The foot may then be

fastened to the table by means of two hinges, so that the screen may be folded down when the position of the lamp is being verified, and may be easily replaced.

The second dark screen consists of a piece of black velvet or black cloth, 350 mm. square, stretched on a frame and supported so that its lower edge is 150 mm. above the table. In this is cut a hole 50 mm. square with its lower edge 380 mm. above the table. This screen is placed close to the photoped, but on the opposite side to that facing the lamps, and with the square hole opposite the square hole in the plate of the photoped. To the right side of the frame is hinged a light frame 350 mm. high and 300 mm. wide, with its lower edge 150 mm. above the table. On this also is stretched black velvet or black cloth. This prevents the illuminated dial of the meter or arc of the regulating tap from interfering with the photometric observations, while at the same time it can be readily moved when these are to be observed.

The third dark screen is about 500 mm. long and 750 mm. high. The fourth is about 450 mm. long and 750 mm. high. These may be made of card painted dead black, or of thin wood, and may be placed approximately in the positions shown in Fig. 3.

The fifth dark screen consists of a piece of black velvet or cloth large enough to form a black background to the lamps when viewed from the photoped. It is best placed upon the wall, but if that is inconvenient, or other objects intervene, it should be supported on a stand, but always so as to be at least 300 mm. behind the flames of the lamps.

Two small mirrors are carried on light stands. One of these, made of ordinary flat silvered glass, is vertical, and is so placed as to enable the Gas Examiner, when seated at the photoped end of the table, on moving his head to the left of the second dark screen, to see by reflection the tip of the flame of the 10-candle lamp through the mica window in the tube, C. The other, which should be about 120 mm. in diameter, is convex, and should have a radius of curvature of about 400 mm. It is placed on the observer's right, and is so inclined that it casts a diverging beam of subdued light upon the divided arc of the regulating tap, upon the face of the meter, upon the aërorthometer, and upon the Gas Examiner's note-book.

All the apparatus on the table upon which light can fall, and which might by reflection illuminate the photoped, or catch the eye of the operator, is to be painted dead black; or, if of finished brass, it is to be bronzed before being lacquered.

The correct position of the photoped end of the two burners is to be verified as follows:—Each burner is provided with a measuring rod securely fastened transversely to a cylindrical and shouldered plug which just fits into the steatite ring and rests upon it. The rod belonging to the 10-candle lamp is to be 1·000 metre from the axis of the plug to the extreme point. The rod belonging to the London Argand is to be 1·265 metre from the axis of the plug to the extreme point. Each rod is to be balanced about the plug. Each must be capable of being placed in its burner without disarranging the burner, except in the removal of the glass chimney of the London Argand or the conical shade of the 10-candle lamp. Each rod should terminate in a rounded ivory point. When these rods are placed in their burners and the long ends are moved gradually round towards the photoped, they should just come in contact with the paper under the clamping plate at the middle point.

A third rod is provided with two plugs, one to fit each burner, and with their centres exactly 0·522 metre apart. The two plugs should just drop into the steatite rings of the two burners. If any one of these tests shows the burners to be incorrectly placed, their position is to be altered until all the measurements are correct. After this process the burners are to be lighted, the flames turned low, and the reflection of one is to be observed over the other on the glass of the photoped. If the reflection appears central, the photoped is symmetrically placed with respect to the two burners; if not, the nut on the standard is to be loosened and the plate turned, until the reflection is central. The two lights are then to be turned up and the slit is to be moved in or out until the two rectangular spaces illuminated by the two lights just meet but do not overlap.

A pattern table photometer is set up in the Gas Referees' office. This may be seen after permission in writing has been obtained from the Referees.

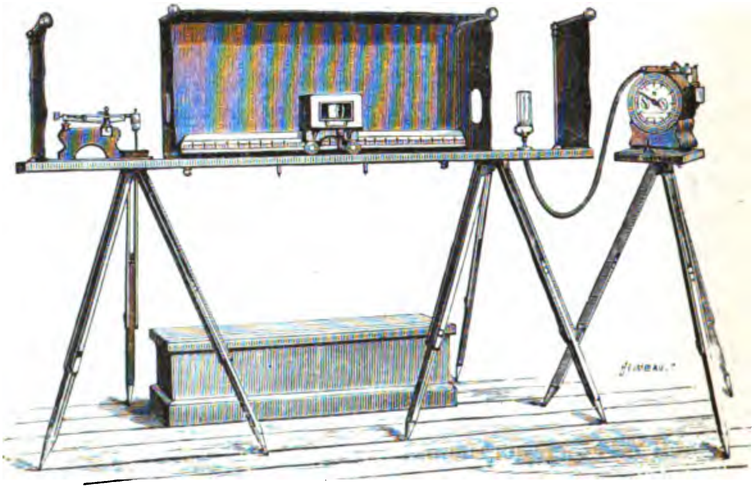

Fig. 13.—Dibdin's Portable Photometer.

The photometer introduced by Mr. Harcourt, above described, is now made in a form in which it can be readily packed for transit, so that this instrument comes also under the head of portable photometers.

Dibdin's Portable Photometer (Fig. 13).—This instrument was devised in conjunction with Messrs. Sugg and Co., in 1884, to provide a ready means of testing the illuminative value of the gas supplied in different parts of the metropolis away from the official testing places, as it was found that whilst the gas would often be up to the full standard quality at the fixed stations, the illuminative value was frequently below the standard at points elsewhere. Up to the present time, the indications of this instrument have no legal value.

This form of portable photometer combines all the essentials of a complete Letheby photometer. It is easily packed away in a box for transit, and can be set up ready for use in five minutes. It consists of a base-board, hinged in the centre for folding. On to this is screwed the photometer bar, on which the disc box travels. The gas burner and candle-holder, or standard, as the case may be, are fitted into metal sockets provided for that purpose in the base-board. Velvet curtains are provided for cutting off extraneous rays of light which might fall upon the disc and the observer's eyes. The base-board is supported upon camera tripods, as also is the experimental test meter for measuring the volume of gas consumed in the process of testing. The instrument is complete in every way, and has passed the criticisms of the London Gas Referees, who would doubtless have sanctioned its use for official testings had they not been bound by the existing Acts of Parliament to restrict these to fixed stations.

Hartley's Portable "Universal" Photometer.—This consists of a light, narrow table, 11in. wide, 2ft. 6in. high, and 5ft. 6in. in length. The scale is divided into inches and tenths, and is 21in. in length. It is fitted into, and capable of being fixed at, any position within a groove in the table top, which has a long slot along its centre, below which slot is a brass socket connected by wire cords passing over pulleys to the winch handle, similar to the arrangement in the Evans photometer for moving the candles, and serving the same purpose, viz., the movement of the standard. The disc carrier is supported on a stand, the base of which is fitted with a pointer or index, coinciding with the vertical line of the disc. The disc carrier, like the scale, may be shifted along the table, both being shifted at the same time, the index of the disc carrier and the zero of the scale always being made to coincide with each other. With the photometer a strong sliding pillar is provided, which, like the photometer, stands upon the floor, and is provided with levelling screws and plumb-lines. This pillar serves to carry gas burners or lamps of various sizes, as required.

CHAPTER III.

RADIAL PHOTOMETRY.

WHEN the Committee of the Gas Section of the International Gas and Electrical Exhibition, held at the Crystal Palace in 1882-3, invited the late Professor William Foster and the author to report upon the various burners exhibited, one of the first points considered at the request of the Committee was the estimation of the angular rays emitted from the various burners submitted for examination. For this purpose Hartley's "Universal" photometer was employed after certain alterations had been made at the author's suggestion.

These alterations were described by the writer in 1884, as follows:—

* As originally designed, the disc was rigidly fixed in the usual vertical position, but at our request this was so arranged as to be susceptible of adjustment at any required angle, so that the rays from the standard and the burner under examination, whatever its position, might impinge upon the screen at equal angles. The following considerations will show our reasons for this:—When two lights are opposed to each other in a horizontal direction, and a vertical screen is placed between them, it is evident that the rays impinging thereon must do so in accordance with the well-known law of the squares of the distances. If the actual distance of one of the lights from the screen remains constant while travelling through the circumference of a circle, whose centre is coincident with the centre of the disc, the number of rays impinging upon the unit area of the disc must be less, and continue to decrease, as the

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* *Journal* of the Society of Chemical Industry, May 29th, 1884.

position of the light is increased from that of the horizontal line; and this decrease is in exact ratio to the cosine of the angle formed by the position of the light with regard to the disc and the path of horizontal rays. Therefore the number of rays impinging upon the vertical disc will diminish with the cosine of the angle thus formed. The following diagram, Fig. 14, shows this very clearly.

Let AA^1 BB^1 represent the section of horizontal rays impinging at right angles upon the vertical disc CC^1, and CDC^{11} D^{11} the section of an equal number of rays thrown at a downward angle from a source of light placed above the horizontal. It is evident that the whole of the angular

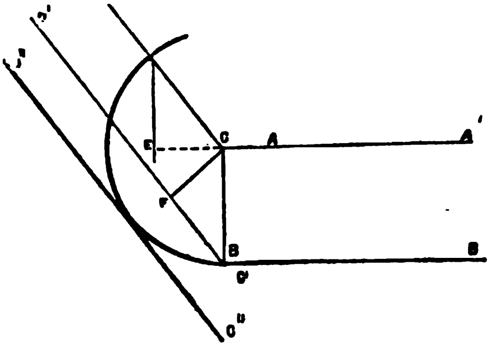


Fig. 14.

rays do not impinge upon the disc CC^1, but that the rays which do so are defined by CDC^1 D^1. By drawing the circumference of a circle whose radius is CC^1, and finding the cosine CE, it is at once seen that the section of the rays CF, which impinge upon the disc, is in exact proportion to the cosine of the angle of incidence CE. When the light is raised throughout a quadrant, the number of rays impinging upon the vertical disc will be *nil*, and thus, although the burner may be one of high illuminating power, such a system of photometry would fail to record any value for it.

Another important point in connection with the vertical

Table I.—*Rays from Burner* 22·5 *deg. with Horizontal Line.*

Readings with disc vertical.	Corrected for cosine of angle = ·9239.	Readings with disc arranged for equal angles of incidence.	Loss per cent. by estimation of vertical disc, due to reflection.
38·7	41·9	44·1	4·9
205·0	222·0	245·0	9·4
453·5	491·0	519·5	5·5
27·0	29·2	29·7	1·6
326·0	353·0	352·0	—
62·8	68·0	68·8	1·1
26·5	28·7	30·8	6·8
140·5	152·1	162·2	6·1
	Average		4·4

Rays from Burners 45 *deg. with Horizontal Line.*

Readings with disc vertical.	Corrected for cosine of angle = ·7071.	Readings with disc arranged for equal angles of incidence.	Loss per cent. by estimation of vertical disc, due to reflection.
20·2	28·6	34·9	18·0
282·5	400·0	491·5	18·6
20·6	29·2	34·2	14·6
47·5	67·2	87·3	22·0
23·7	33·6	38·4	12·5
49·4	70·0	85·8	18·4
42·5	60·2	67·1	10·3
15·6	22·1	25·2	12·3
81·0	114·8	136·5	15·9
124·1	176·0	186·9	15·8
104·2	147·8	161·9	8·7
15·7	22·2	25·1	11·6
88·2	125·0	144·0	13·2
14·5	25·5	25·7	0·8
9·2	13·0	12·7	—
129·3	183·0	207·0	11·6
9·0	12·7	12·6	—
52·2	74·0	86·5	14·5
	Average		12·15

Rays from Burner 67·5 *deg. with Horizontal Line.*

Readings with disc vertical.	Corrected for cosine of angle = ·3827.	Readings with disc arranged for equal angles of incidence.	Loss per cent. by estimation of vertical disc, due to reflection.
55·3	144·5	378·0	61·8
82·8	216·5	920·0	76·5
	Average		69·1

disc must not be overlooked, and that is, that when the rays of light impinge upon a surface at an oblique angle, a considerable loss of light occurs by reason of the increase of reflection and absorption, which preponderates over the loss incurred when the angle of incidence forms a right angle. This loss increases with the increase of the angle, and seriously vitiates any results obtained. Table I. shows the results of some tests made in this manner, and gives the illuminating power of angular rays when tested with the photometer disc fixed in a vertical position, and when it is arranged so that the angles of incidence are identical.

After correction for the diminished number of rays impinging upon the disc at the different angles, the value obtained is deducted from that found by estimation with the disc arranged for equal angles of incidence, and the difference between the two results calculated into percentages. By this means it is seen that when the burner is at an angle of 22·5 deg. above the horizontal, the average loss due to reflection from the vertical disc is 4·4 per cent., at 45 deg. it is 12 per cent., and at 67·5 deg. 68 per cent. It is obvious, therefore, that the method of estimating the illuminating power of angular rays by means of a vertical disc is erroneous.

The following diagrams represent the results obtained by the radial photometer when various light sources of different character are measured by it.

By arranging the disc so that the angle of incidence is equal on either side, thus (disc, AA^1; horizontal rays, AB, A^1B^1; angular rays, CA, C^1A^1), we equalise both the proportionate number of rays impinging thereon, as well as the loss due to reflection. Determinations thus made possess all the value of those made with a vertical disc and horizontal rays on either side in the usual manner.

The Radial Photometer.—The principle involved in the construction of the Radial photometer is very simple—viz., that the light under examination should be rigidly fixed in one position, while the estimations of the value of the angular rays emitted from the horizontal to the vertical, either above or below, are being made; thus ensuring perfect steadiness of the burner, or other luminous point.

The apparatus (Fig. 15) consists of two vertical supports, one of which is permanently fixed to the base-board or foot, while the one on the right hand travels on rollers on the base-board in such a position that it will run in front of the fixed support.

The two uprights are connected by a bar, the ends of which work upon trunnions or axles attached to blocks, which travel in the grooves of the uprights. These blocks can be clamped in any desired position. One end of the bar is attached to the front of the fixed upright, while the other end is attached to the travelling upright at the back; so that, when the two uprights are in juxtaposition, the bar is perpendicular between them. The centres of the trunnions correspond in position with the centres of the two graduated dial plates in front of the uprights. The distance between the centres of these dial plates is 50in. It is therefore evident that, whatever *position* the bar may be in, the *distance* from the centre of one dial to that of the other must be constant. In front of the dial plate on the travelling upright the screen or disc-holder is fixed, so that its centre is coincident with the centre of the dial.

Attached to the block in the groove of the travelling upright support is the horizontal bar carrying the standard. The standard is supported in front of the horizontal bar by a travelling carriage, working on rollers, and is moved by a cord and winch, conveniently placed on the right-hand side of the graduated dial on the support. Attached to the block carrying the photometer disc is a brass rod, which is brought well forward, and then curved round for the purpose of carrying a velvet curtain to screen off extraneous light when readings are being taken.

The two dial plates are graduated—the larger one on the fixed support in degrees, and the smaller one on the travelling support in half degrees, which are numbered as whole degrees for the purpose of facilitating the setting of the disc for equal angles of incidence; so that when the bar is set (say) at 40°, the disc-pointer is to be set at 40°. It will then be in the proper position—viz., 20°. The disc may be arranged to work automatically with the movement of the bar, by means of a simple mechanical appliance; so that, whatever may be the position of the bar, the disc will be at the correct angle.

A brass rod is provided for adjusting the position of the burner, &c., to be tested. It has to be pushed through the centre of the block and trunnion on the fixed upright support, and will then be at right angles with the plane of the dial, and project exactly through its centre, by which means it is easy to adjust the flame in its proper position in front of the apparatus. The light to be tested may be brought forward to the full extent that can be attained by the disc and standard, which, obviously, can be regulated as desired, so that the size of the burner or lantern to be tested by this apparatus is practically unlimited, due regard being paid to the length of the bar and the power of the light.

When a test is commenced, the light to be examined is fixed on the support attached to the block in the fixed upright, and accurately centred with the dial plate, which is to be lowered to the bottom of the groove in the support. The block in the travelling support has next to be raised, which operation will bring it immediately over the burner; the travelling upright being in front of the fixed support, and the pointer on the bar indicating 90° on the large dial plate. The photometer disc is to be arranged for equal angles of incidence, by turning it until its pointer is at 90, when a reading can be taken. The clamp holding the top block in position is then loosened, and the handle working the rack and pinion of the travelling support turned until the bar is at an angle of 80°. The block must then be clamped, the disc adjusted to 80, and so on for each degree or ten degrees as desired, until the horizontal rays are estimated. The block supporting the light is then to be raised to the higher position, and the bar adjusted for the desired angle below the horizontal, and a second series of readings taken until the downward vertical rays are estimated. Fig. 15 shows the instrument arranged for testing the rays thrown downward at an angle of 45°.

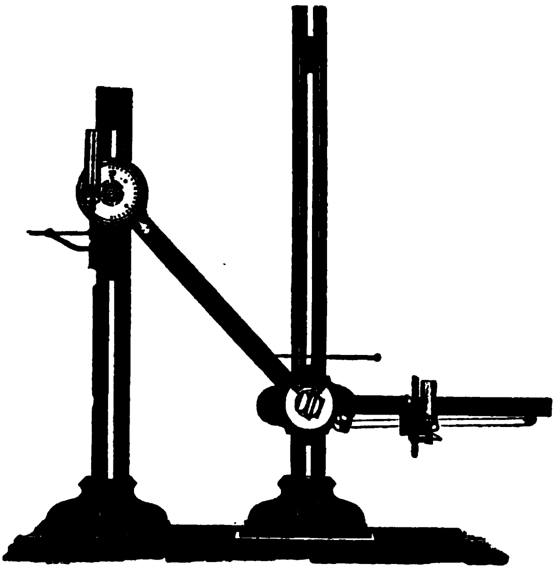


Fig. 15.—Dibdin's Radial Photometer.

It is to be hoped that in future all comparative tests of the value of various burners will be so conducted as to show the actual work done by them, not only in one direction, but in all directions. With Argand and other circular burners, this can be done by making one series of tests from the vertical above to the vertical below at every 10°. But in the case of flat-flame burners, it is necessary that this series should be made in duplicate, one with the flame flat, or at right angles to the bar of the photometer, and one with the flame placed with its edge to the bar. An extensive series of experiments on this point has shown that very considerable differences exist between the quantity of light emitted from the flat surface and from the edge of various burners; this difference varying from

TABLE II.—*Flat Flame Burners. Illuminating Power of Horizontal Rays.*

Position of flame.	Burner No. 1 candles.	Burner No. 2 candles.	Burner No. 3 candles.
Flat to photometer bar... ...	30·8	24·2	8·5
Flame turned 10°	30·8	24·2	8·5
,, ,, 20	30·9	24·3	8·5
,, ,, 30	30·9	24·2	8·5
,, ,, 40	30·8	24·0	8·4
,, ,, 50	30·2	24·0	8·3
,, ,, 60	30·1	23·8	8·2
,, ,, 70	30·2	23·5	8·2
,, ,, 80	29·8	22·4	8·2
Edge to bar ,, ,, 90	24·4	20·3	7·9
,, ,, 100	28·7	21·6	8·2
,, ,, 110	29·6	22·8	8·3
,, ,, 120	30·3	23·5	8·3
,, ,, 130	30·5	23·4	8·3
,, ,, 140	30·5	23·2	8·3
,, ,, 150	30·5	23·4	8·4
,, ,, 160	30·1	23·5	8·4
,, ,, 170	30·4	23·2	8·3
Flat to bar ,, ,, 180	30·3	23·1	8·4
,, ,, 190	30·4	22·8	8·4
,, ,, 200	30·8	23·0	8·4
,, ,, 210	30·8	22·7	8·4
,, ,, 220	30·7	22·9	8·3
,, ,, 230	31·0	22·9	8·3
,, ,, 240	30·6	22·8	8·3
,, ,, 250	30·1	22·0	8·2
,, ,, 260	29·5	21·2	8·1
Edge to bar ,, ,, 270	25·0	18·6	7·8
,, ,, 280	28·5	20·6	7·8
,, ,, 290	29·5	21·9	8·1
,, ,, 300	29·7	22·2	8·3
,, ,, 310	29·8	23·0	8·3
,, ,, 320	30·8	23·0	8·4
,, ,, 330	30·3	23·5	8·3
,, ,, 340	30·5	23·4	8·4
,, ,, 350	30·7	23·5	8·4
Flat to bar ,, ,, 360	30·9	23·4	8·5

10 to 35 per cent. of the light emitted from the flat surface Therefore, it is very necessary that the two series of tests should be made, and an average taken, which should be held to represent the value of the burner.

For the purpose of facilitating comparison, the author has made determinations of the quantity of light afforded in all directions horizontally by three classes of flames, testing them at every 10°. The results are stated in

TABLE III.—*Flat Flame Burners. Illuminating Power of Angular Rays.*

Direction of rays.	Burner No. 1 candles.	Burner No. 2 candles.
90° above horizontal	27·8	8·0
80 ,, ,, ...	29·2	9·0
70 ,, ,, ...	29·0	9·3
60 ,, ,, ...	30·5	9·3
50 ,, ,, ...	30·8	9·2
40 ,, ,, ...	30·9	8·7
30 ,, ,, ...	30·3	9·4
20 ,, ,, ...	30·4	9·3
10 ,, ,, ...	29·4	9·3
Horizontal	29·8	9·7
10° below horizontal	29·9	9·9
20 ,, ,, ...	30·2	10·0
30 ,, ,, ...	30·2	10·1
40 ,, ,, ...	29·8	10·0
50 ,, ,, ...	29·8	10·0
60 ,, ,, ...	30·0	10·7
70 ,, ,, ...	29·2	10·3
80 ,, ,, ...	28·7	11·2
90 ,, ,, ...	19·6	5·8

Table II., page 68. The diagrams (Plate II.) show at a glance the positions in which the maximum light is thrown.

The value of the Radial photometer is most strikingly shown in the examination of burners shaded by globes, reflectors, &c. For this purpose the author has tested three Argand burners, fitted with different forms of shades. Table IV., page 70, contains the results, which are also put in diagram form. Two of these sets of observations clearly indicate that the form of the porcelain cup might be

TABLE IV.—*Effect of Reflectors and Shades.*

Direction of rays.	Argand No. 1.			Argand No. 2.			Argand No. 3.		Christiania.		Union.	
	Without shade, &c.	With reflector only.	With reflector and cup.	Without shade, &c.	With reflector only.	With reflector and cup.	Without shade, &c.	With paper reflector.	Without globe.	With globe.	Without reflector.	With compound reflector.
90° above horizontal	16·8	27·6	33·0	19·0	25·0	29·0	10·6	9·3	—	17·6	—	—
80 " "	20·0	30·8	36·6	21·0	29·0	33·0	14·0	13·7	14·0	18·4	—	—
70 " "	17·4	24·4	31·2	19·4	21·4	28·4	14·2	12·9	14·1	19·3	8·7	9·2
60 " "	18·2	14·8	21·0	18·8	13·8	19·2	15·0	11·0	13·4	10·3	8·7	9·2
50 " "	18·6	11·2	14·8	18·8	10·0	14·0	15·0	4·0	13·6	8·4	8·7	9·8
40 " "	18·8	9·8	12·8	18·4	8·4	11·0	15·1	1·3	12·8	8·0	8·6	10·4
30 " "	18·6	9·0	11·8	17·0	7·8	9·2	15·1	1·3	13·0	7·0	8·7	12·6
20 " "	18·6	7·6	10·1	17·2	6·4	8·4	15·0	2·0	12·4	6·5	8·8	19·6
10 " "	18·6	6·2	8·8	16·8	5·4	7·2	15·0	1·0	12·3	6·7	7·2	50·0
Horizontal	18·6	5·2	8·6	16·8	4·8	7·6	15·0	0·0	12·2	7·0	6·6	28·0
10° below horizontal	18·8	14·4	13·8	17·2	16·0	15·0	15·6	2·0	12·3	7·6	—	—
20 " "	19·2	24·2	15·6	17·8	21·6	14·2	15·8	12·5	18·0	7·6	—	—
30 " "	18·2	25·6	12·2	17·2	23·0	12·0	15·6	25·4	12·7	8·0	—	—
40 " "	16·4	26·0	11·8	16·8	23·4	13·4	14·0	31·0	12·8	9·0	—	—
50 " "	15·2	24·8	13·2	14·4	23·4	16·2	12·3	30·8	12·3	15·0	—	—
30 " "	11·2	22·0	17·4	11·0	20·0	19·4	8·4	30·0	11·6	17·2	—	—
70 " "	6·0	18·8	20·8	6·2	17·0	23·4	4·8	29·4	10·8	15·1	—	—
80 " "	2·6	21·2	21·8	4·0	20·8	25·2	2·5	33·0	6·3	10·3	—	—
90 " "	2·0	25·6	26·6	2·0	20·2	23·6	1·0	30·4	1·6	7·0	—	—
Average	15·46	—	—	15·26	—	—	12·31	—	11·73	—	—	—

arranged to yield more satisfactory results, but considering the want of a suitable method of testing, before the Radial photometer was introduced, there is little room for complaint. The effect of the well-known glazed-paper shade is very striking; the even distribution of light downward being very satisfactory. The tests of a Christiania burner, with and without its globe, are also interesting; but, as in this case the globe has to do the double duty of regulating the draught and reflecting the rays in a downward direction, it is difficult to see how its form can be improved. The tests of a new form of reflector well illustrate the character of the work of which the Radial is capable. The tests may be taken at every degree where necessary, and thus most valuable comparative results are obtained.

The effect of a suitable reflector in diffusing the power of the light in particular directions is very marked; so much so, that in future competitive tests of burners and apparatus relating thereto, it would be highly desirable to make special awards for the best form and diffusing power of reflectors, In the author's judgment, the most perfect reflector should throw the rays of light in such a manner as to evenly illuminate a level surface comprised within a circle whose circumference includes those rays falling at an angle of 30° below the horizontal.

The nearest approximation to this definition is the result given by the well-known porcelain shade supplied with Argand burners. When the cup is in position, the rays falling at all angles from 0° to 60° below the horizontal, are intercepted to an excessive extent.

The importance of facility in testing a new disc for photometric readings is generally acknowledged. The form of carrier used with the Radial photometer is especially adapted for readily adjusting the disc, so that either side may be turned towards the standard light. It is only necessary to loosen the screw holding the carrier, when the latter can be rotated on its axis. It may be of interest to point out that this is the first photometer to which the author's rotating disc-holder, now coming into very general use, was applied.

Harcourt's Holophotometer.—The following description of this photometer is extracted from the *Journal of Gas Lighting*, July 17th, 1888:—

The holophotometer has been designed in order to get rid of two difficulties connected with other methods of attaining the same object, viz., to measure the light emitted in every direction by any luminous source. These difficulties are:—(1) The movement of the light to be measured or of the standard lamp, neither of which is desirable. (2) The errors caused in the measurement of lamps provided with reflecting fittings, by the assumption that the flame is the zero point from which measurements should be made, whereas, strictly speaking, the principal focus formed by the reflector should be taken as the zero point. Inasmuch, then, as this focus may be several inches away from the flame, and as the length of the bar usually employed is 60in., it is evident that serious errors may be introduced by the difference between the real and the assumed zero point.

To establish the existence of such an error, and to eliminate it, two things are necessary, viz., that readings should be taken with bars of various lengths; and that the length of the bar should be very great compared with that between the real source of light and the focus formed by the reflector. Both these points are secured by the use of the holophotometer. The instrument is mounted upon a table capable of being moved nearer to, or further from, a fixed table containing a graduated bar with movable disc (say, of the Letheby pattern), and having a standard lamp fixed at the zero of the bar. The lamp to be measured is mounted upon, or is in rigid connection with, the movable table; and it is therefore not moved during a series of readings.

The holophotometer consists of an axis working friction tight in a collar supported by a vertical pillar. The axis is accurately fixed at the same height as, and in a line with, the centre of the disc. At the end nearest to the disc is placed a large mirror, with its centre concentric with the axis, but so arranged that the plane of the mirror may be inclined and clamped at any angle to the axis. At the other end of the axis is fixed a telescopic arm, carrying a smaller mirror, which is capable of being turned into any required position. The arm being rigidly fixed to the rotating axis of the instrument, to which is also attached the larger mirror, it follows that the rotary motions of the mirrors about the axis are identical. The angles of rotation are measured by the indications upon a divided circle attached to the moving axis, and are shown by a pointer fixed to the upright support.

The mirrors are adjusted in such a way that the light from the lamp to be measured falls upon the smaller mirror; thence is reflected on to the larger one; and finally along the axial line of the photometer disc. As both mirrors rotate together, it follows that if a horizontal beam is reflected correctly, all other beams will find their way along the axis of the photometer. If, therefore, the arm carrying the small mirror be moved through various angles, it will receive the light emitted from the lamp at those angles, and the light will at every angle be transmitted along the axis of the photometer. The divided circle is made large enough to serve as a complete screen of all direct light; and only the light falling on the small mirror can find its way to the disc. In order that absolute, as well as comparative, tests may be carried out, only one additional measurement need be made. The direct horizontal light is measured without the interposition of the holophotometer (which is mounted so as to be easily moved out of the direct line); then the mirrors are interposed, and a new measurement is made. The additional path travelled by the light is allowed for in calculation; and thus the absorption of the mirrors is determined once for all for the particular character of light under measurement. It is only necessary afterwards to multiply subsequent values by this coefficient of absorption, in order to obtain absolute measurements at various angles. The absorption of the two mirrors employed is stated to be only 1·8 per cent.

The employment of mirrors in photometry has sometimes led to serious errors; but it will be seen by the foregoing description that, inasmuch as the relative angle of the mirrors is never changed, and as their absorption is easily calculated and allowed for, the only objections to their use have been guarded against and avoided.

In order to eliminate the second source of error mentioned above—viz., that arising from the formation of a principal focus—it is only necessary to take a series of readings with the table in one position, and then move it to a greater distance and take another series. If a focus is formed at a sufficient distance to produce an appreciable error, it will clearly appear in the difference between the readings at the two distances; and then it is only necessary to wheel the table to such a distance that the discrepancy is inappreciable. In other words, this is equivalent to using a bar of sufficient length to make it practically infinite compared with the distance between the focus and the real source of light.

The instrument has been designed specially for use in lighthouse work, where it becomes of the highest importance to measure accurately the total light given by any lamp, and not only that emitted in any one particular direction, which may or may not be the maximum.

Sugg's Travelling Photometer.—As this instrument, shown on page 75, has been chiefly used for testing the illumination of pavements and roadways, and consequently those rays emitted at various angles, it comes under the head of angular photometers.

The apparatus consists of a box with ventilating top, in which a Keates sperm oil lamp is fixed. The light from the flame is reduced to that equal to two candles by means of a slit in a metal screen placed horizontally across the centre of the flame. The light from the slit passes through one side of the box through a wooden tube to a companion disc, shaped like the letter A, and covered on both sides with white paper. A newspaper cutting is patched over the edge of the disc, so that a portion of the print is on each side of it. The two sides are separated by a partition which is carried up some distance above the discs. One side—that nearer the lamp—is covered so that no other light but that of the lamp can fall upon it; the other side is left open to receive the full light from the electric or other light to be examined. A mirror properly placed enables the observer to see both sides of the disc at once, and thus to judge of the relative amount of light falling on each. The standard degree of light adopted is therefore equal to that which will fall on a white surface from the

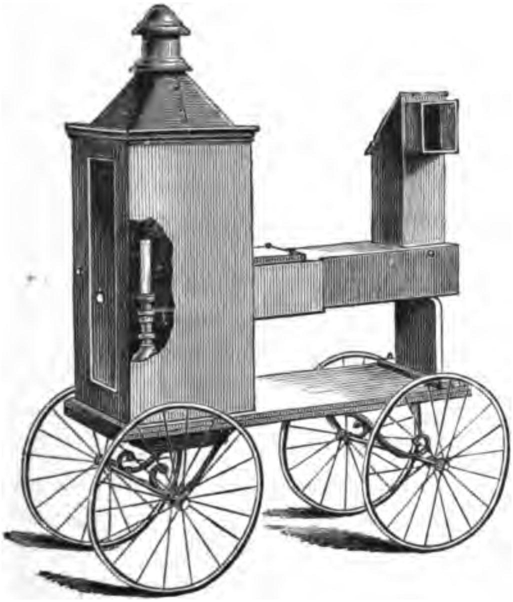


Fig. 16.—Sugg's Travelling Photometer.

rays of two candles placed at a distance of 3ft. from that surface. The photometer as thus used is on the Church and Mann principle; but it may be arranged on the King principle, and thus be used to measure the amount of light falling in any part of a roadway at a distance of 3ft. from the ground.

Some of the results obtained by the use of this instrument were given by Mr. W. Sugg in a paper read by him before the Gas Institute some time since, and will be referred to later on in connection with the subject of street illumination. At present our subject relates merely to different methods of estimating luminous energy.

In connection with the distribution of light in public places, Mr. Trotter contributed an interesting paper to the Institute of Civil Engineers in 1892, when he described the following arrangement (Fig. 17) devised by himself for this purpose.

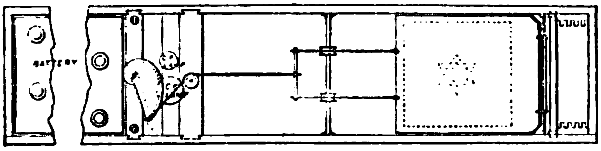
A small electric lamp was mounted in a box, so that it stood 5in. above the ground. The current was obtained from a battery of four Lithanode cells, two of these being capable of running a ¾-candle lamp at a fair brightness for ten hours; but in order to allow a good margin, two more cells were connected in parallel. These proved to be sufficient for the purpose, and no appreciable change in candle-power was observed between the preliminary calibration and the one which followed each evening's work. A slightly higher power is given immediately after charging, but a quarter of an hour's continuous discharge seemed to bring the battery into a very steady condition. The lamp was lighted for as short periods as possible, about ten seconds being sufficient for each reading.

The light from this lamp was received on a reflecting screen made of white Bristol cardboard mounted on an axis passing through its upper edge, and was arranged so that it could fold up quite out of the range of the beam of light from the lamp.

Above the reflecting screen, a simple cardboard screen with a star-shaped hole cut in it was fixed in a horizontal position, so that the observer when looking down on the box would see the reflecting screen through the star-shaped opening. The Bunsen screen should be at least 3½in. square, and the star-shaped hole should be not less than 1¼in. across.

The method of observation consisted in inclining the reflecting screen at different angles. In order that a convenient scale might be provided, motion was given to the reflecting screen by a fine chain wound upon a snail cam

Fig. 17.—TROTTER'S PHOTOMETER.



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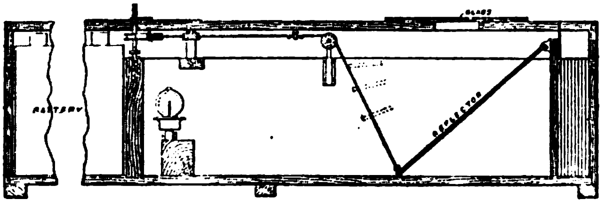

Sectional Elevation.

The cam was designed upon the assumption that the illumination on the screen would be proportional to the cosine of the angle of incidence of the light upon it. This is not strictly the case, especially as a convex lens was used in many of the experiments to increase the available light from the electric lamp.

The object of the snail cam was merely to spread the divisions of the scale more evenly, and did not aim at uniform division. The scale was empirically calibrated with a standard candle.

The principal object of the measurements of illumination made with this instrument was to ascertain the nature of the distribution of light in various streets and public places; a second object was to find the amount of illumination in candle-feet for such places; and the third to deduce the candle-power of the lights which produced that illumination.*

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* Trotter, "The Distribution and Measurement of Illumination," "Proceedings," Inst. C.E., vol. cx., part iv.

Illuminating Value of Coal Gas.

CHAPTER IV.

ILLUMINATING VALUE OF COAL GAS.

THE chapters dealing with the standards of light and the photometer must be read with the following, which only relates to that part of the subject specially dealing with photometry in relation to the estimation of the value of coal gas as to its illuminating power. The legal test of the gas in this respect consists in burning the gas at the specified rate of 5 cubic feet per hour in a standard burner, and measuring the rays emitted therefrom in a horizontal direction only. As previously explained, the standard of light employed in London is in a transition state, candles being used in the older pattern photometers, but in the stations altered under the prescription of the Gas Referees the modified pentane Argand is employed by agreement with the gas companies. In the Provinces this alteration has not yet been made, although it is anticipated that in the future a similar change will be effected.

The photometer and standard having been provided, it is essential that the following additional apparatus be fitted thereto, viz.:—

(1) An experimental wet meter indicating the rate of consumption of the gas by a long hand, which makes one complete revolution on the dial in one minute for every 5 cubic feet of gas consumed per hour. By this arrangement the rate of consumption is readily ascertained by comparing the rate of movement of the meter hand with that of the seconds hand of a stop watch or clock.

In most modern meters employed for this purpose a clock attachment is mounted on the top of the meter, which actuates a second hand travelling over that of the meter, so that when the gas is passing at the prescribed rate of 5 cubic feet per hour the two hands travel together.

(2) A delicately balanced governor to ensure an even rate of flow of gas to the burner during the period of testing.

(3) A micrometer cock, by means of which the rate of consumption can be adjusted with the greatest accuracy.

(4) Syphons on all the connecting pipes, by means of which any water accumulating in them can be conveniently removed by turning on the syphon taps for a few moments.

(5) In order to enable the operator to ascertain the pressure of the gas flowing through any part of the apparatus, a delicate pressure gauge, known as King's gauge, should be fitted by connecting pipes to (*a*) the inlet of the meter; (*b*) the outlet of the meter; (*c*) the outlet of the governor; and (*d*) to the supply to burner after passing the micrometer cock.

(6) It is also convenient to have a separate stop clock to time the rate of combustion of sperm by the candles, when these are employed. With the pentane Argand this is not required.

The following instructions were given by the author in his work on "Practical Photometry," already referred to, for testing the accuracy of the respective part of the above apparatus.

Syphons.—The pipes under the photometers are to be cleared by opening the taps on the bent syphon-pipes until all water condensed therein drains out, when the taps are to be carefully turned off.

Meters.—The water-line is to be noticed; and, if incorrect, the proper quantity of water must be added, or removed, until the true level is obtained. In the case of meters which have been repaired, the original line on the glass is sometimes incorrect; and a new one is best indicated by a mark on the case by the side of the glass. When once this is done, it will remain true until the meter has again been to the makers for further repairs, when the true line must be again ascertained. The meter is then tested by the cubic-foot bottle according to the instructions laid down by the Gas Referees.

The King's Gauge has now to be seen to; and the water-line and pointer, if necessary, adjusted as already described.

The Balance Governor is next examined, and water added if required.

Test for Leakage.—Remove the standard burner from its support, which is done by lifting it out of its socket or unscrewing, as the case may be; and screw on the cap provided for this purpose over the pipe. Then turn the gas full on, and note the long hand of the meter. At first a small quantity of gas will pass until the pressure is equalised, after which the meter hand should remain steady. This being satisfactory, the burner is replaced and the gas lighted.

King's Gauge.—Next test the apparatus by means of this gauge. Open the outlet tap on the side, and shut off all inlet taps, when the pointer will fall to zero. Shut off the outlet tap, and open that indicated as "inlet of meter." The pointer should indicate a little over 1in. In case this should not be so, adjust the weights, or screw, on the initial governor under the bench until the proper pressure is obtained, when the inlet tap to the gauge is shut off.

Next open the tap marked "outlet of meter." The pointer should fall back from one to two-tenths. If it fall more than this, probably the meter bearings require a little oil, which is applied by putting a few drops in the slanting pipe at the back of the meter. Then shut off the "outlet of meter" tap; and open that marked "outlet of governor." The pointer should again fall back, and indicate from six-tenths to seven-tenths. In case it does not do so, obtain that pressure by increasing or decreasing the weights on the balance governor, which will then work satisfactorily. In like manner ascertain the pressure after the regulating cock, or "point of ignition," as it is sometimes called. As before stated, this is a quantity which slightly varies with different burners; but, when once ascertained, it is a useful guide.

If these operations are carefully performed, the gas-carrying and regulating portion of the apparatus will be known to be in good order, and the tests may be proceeded with, after the following further examinations have been satisfactorily made.

Standard and Meter Clocks.—These are to be carefully compared over a period of ten minutes. The error of the meter clock should not exceed two seconds in that time. If it is more than this, the glass face is removed and the regulating index slightly altered, until on further trials the two clocks work together.

Candle-balance.—This should be clean and free from dust and droppings of sperm from the candles, especially under the candle-holder, as a very slight quantity is sufficient to cause the balance to "stick," and so give erroneous results. The candles are to be placed in position and lighted, when they must be counterpoised and the time noted for the candle end of the balance to rise and come to rest. This should not exceed five or six seconds. If it is greater or less than this period, the balance must be adjusted by screwing the ball on the top up or down until on further trials the proper rate is attained.

The Disc.—After having adjusted the gas-flame to about 5ft. per hour, and placed the candles in good burning condition in the balance, proceed to take a series of readings; and then reverse the disc and again read. This is to be done several times; and the mean results of the readings, with the disc in each position, noted. If the disc and mirrors are in good order, the results should be alike; but, if they disagree, a new disc is to be put in position, and the operations repeated, until a good disc is obtained. In the case of an Evans photometer, these readings should be made with the two end doors open.

The Velvet Curtains, &c., of the photometer should be kept free from dust, which is a great reflector of light, and a dreadful tell-tale of the reliance to be placed on an operator's work.

Cubic Foot Bottle.—For the purpose of correcting the water-line of the meter a properly fitted gas-testing station should be supplied with a means of passing a measured volume of air or gas through the meter. For this purpose the cubic-foot bottle is generally employed.

Although in reality very simple, the apparatus requires care in handling in order to obtain reliable results. It consists of an egg-shaped metal vessel having a capacity between the two water-lines on the top and bottom tubes of exactly one cubic foot. At the bottom there is an inlet tap for the admission of water from an overhead tank or other convenient source. The bottle being empty, this tap should be turned gently to admit a small quantity of water to the bottom glass tube until it rises to the paper mark indicating the lower water-line. The tap is then closed, and the three-way tap at the top—which should, during the above operation have been opened to the external air to allow the air or gas, as the case may be, to escape when the water was admitted—must now be turned so as to open a through passage to the pipe leading to the inlet of the meter. The meter hand must now be brought to zero by passing gas through the meter, and the position of the small index hand denoting tenths of feet carefully noted. The micrometer cock being adjusted to pass gas at the rate of five cubic feet per hour to the burner, the tap admitting water to the cubic-foot bottle must now be carefully opened so as to cause a pressure of gas on the gauge attached to the bottle to indicate 1in. of water pressure. The air or gas in the bottle (gas is now generally employed) will now pass to and through the meter. The gauge must be watched to see that the pressure does not greatly exceed 1in. When the bottle is full of water to the top water-line, which should take twelve minutes, the water supply tap must be shut off, and if the meter is correct the large hand will have made exactly twelve complete revolutions, thereby indicating the passage of exactly one cubic foot of gas through the meter. Should it stop short of the zero mark, it will indicate that the capacity of the meter is too great, and therefore the water-line is too low, and more water should be added in about the proportion of 1 oz. for 1 per cent. of error. If the hand has passed the zero mark the converse is the case, and water should be withdrawn. These operations should be repeated until the meter is correct.

It facilitates the observation of the rate of flow of water into the bottle if this is provided, as formerly suggested by the writer, with a glass water-gauge tube, by means of which the operator can see at a glance how the test is progressing. This, of course, can be done equally well by watching the meter hands, but in practice the gauge is a great convenience, and nearly all cubic-foot bottles are now so provided.

A modified form of this bottle is prescribed by the Gas Referees. This has a capacity of only one-twelfth of a cubic foot.

The record of all tests should be entered at once as they are taken in a book kept for the purpose.

A "test" will consist of the average of ten readings of the photometer disc. These are then to be corrected for the candle consumption, and the result again corrected for variations in the rate of the gas consumed in consequence of its expansion or contraction from the standard volume by reason of the barometrical pressure and the temperature. Tables are provided in the Instructions of the Gas Referees, by means of which the necessary calculations are greatly facilitated. In fact, the operation consists in finding in the table the "tabular number" corresponding to the observed indications of the barometer and the thermometer attached to the meter, and dividing the illuminating power ascertained after correcting for candle consumption.

Further testings are made of the purity of the gas in regard to the quantity of ammonia, sulphur, and sulphuretted hydrogen, but as these substances do not affect our present purpose, they need not here be further referred to. The methods employed, however, are fully given in the Instructions of the Metropolitan Gas Referees, which will be found in the Appendix.

The testings for pressure, however, are most important so far as they relate to the utilisation of the gas and its regulation to the burners; but in regard to the legal aspect it has little practical value, as the standard of $\frac{6}{10}$in. between midnight and sunset, and 1in. between sunset and midnight, is altogether too low to meet the requirements of consumers, who, unless better supplied, would soon inundate the companies with complaints.

In certain cases on high-pressure mains it is necessary to use special high-pressure governors, but these are altogether exceptional cases.

The pressure tests are carried out in London on the street lamps. The examiner has to remove the lantern and fix on the supply pipe a pressure gauge (Fig. 18), specially designed for the purpose by the Gas Referees, a wood-cut of which is given. It will be seen that the arrangement is merely an ordinary U-tube pressure gauge fitted in a special form of lantern. The usual simple U-tube gauge would answer the purpose equally well, as the surrounding casing is merely extraneous and ornamental.

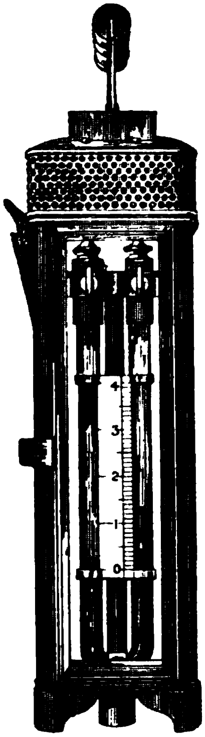

Fig. 18.

In the Gasworks Clauses Act it is stated that the company shall provide a properly-fitted station for testing the illuminating power and purity of the gas, but no specific position is assigned for the station, which is usually that arranged by the company for its own purposes. In the Metropolis Gas Act of 1860, relating to the testing of the London gas, it was first provided that the site of the testing place should be within 1000 yards of the gasworks, but subsequently in 1876 this was altered so as to leave the Gas Referees a free hand in fixing the position of the stations, in order that the gas might be tested in the district in which it was used rather than in the near proximity to the making places.

The necessity for more effective methods of testing the illuminating power of the gas as supplied to the consumers has been frequently pointed out by the writer in the course of various official reports, in consequence of the discovery that the gas supplied in the districts away from the official gas-testing stations was very frequently 10 per cent. and even 20 per cent. below the standard. This fact was also pointed out at Liverpool by Mr. Bellamy, who adopted the system of testing the quality of the gas by the portable photometer, with the result that the supply, although in the hands of a company, was immediately equalised throughout the district, so that all consumers are now supplied with gas of equal value.

CHAPTER V.

JET PHOTOMETER.

A DESCRIPTION of the various forms of photometers would not probably be considered complete without some reference to those instruments which more strictly belong to the class of indicators rather than to light measures. These are the jet photometers and illuminating power meter. The principle of these depends upon the fact that at a given pressure the volume of gas which will pass through a given aperture varies with its specific gravity. On the assumption that the higher the gravity of the gas the greater will be its light-giving property, it follows that the quantity of gas required to yield a flame of given size will vary with its quality, and that this quality may be roughly indicated by either measuring the pressure of the gas at the point of ignition or aperture of outlet, or by measuring the actual volume of gas consumed in a given time.

Whilst each of these factors are open to considerable variation, according to circumstances, yet instruments based upon them are of undoubted value when the coal gas is manufactured under ordinary conditions; but when there is an excess of carbonic acid in the gas, or it is largely charged with "water gas" and petroleum vapour, the conditions became so changed that the indications of the "jet" photometers must undergo careful re-adjustment for each particular quality of gas employed. In short, whilst these instruments are of the greatest value on gasworks as guides to those in charge, they are not photometers, and should never be used as such.

Lowe's Jet Photometer, improved by Sugg.—This instrument (Fig. 19) is a delicate pressure gauge with a jet burner

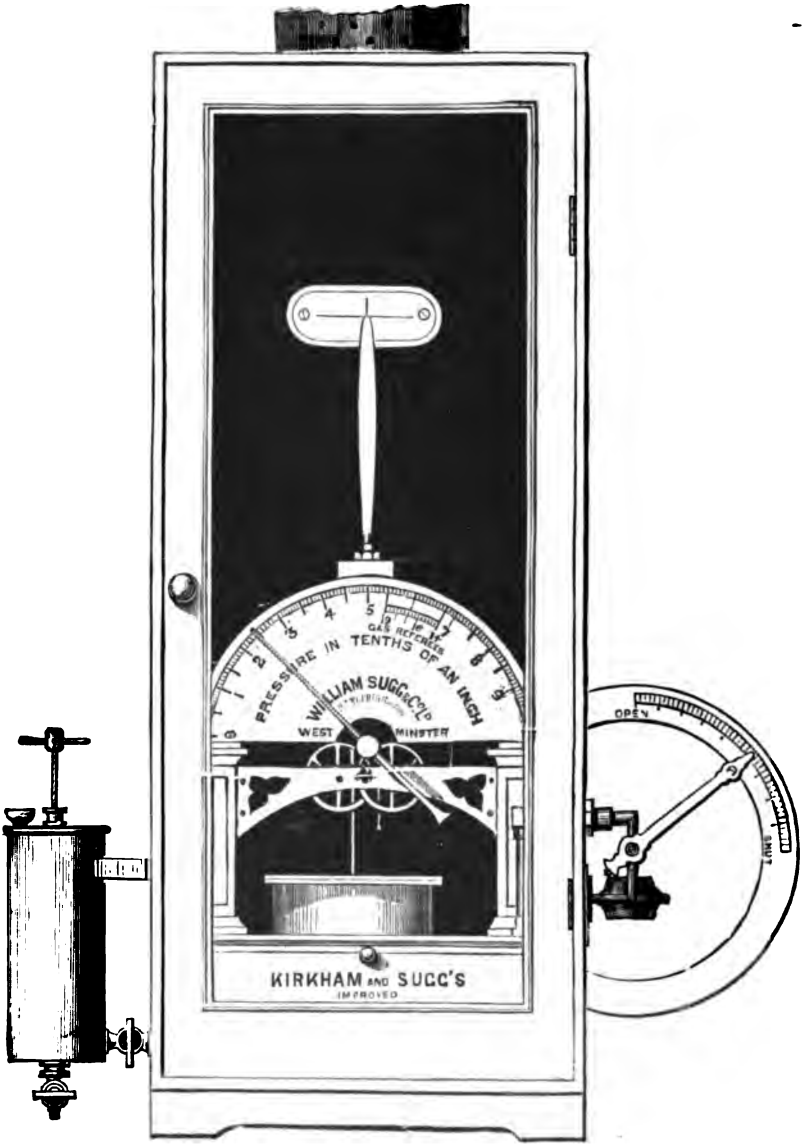
PRESSURE IN TENTHS OF AN INCH
0
1
2
3
4
5
6
7
8
9
GAS REFEREES
WILLIAM SUGG & Co Ld
WEST MINSTER
KIRKHAM AND SUGG'S
IMPROVED
OPEN
SHUT

Fig. 19.

on the top, from which a gas flame 7in. in height is burnt The indicator is a pointer actuated by a float in the body of the instrument, which float is elevated by the pressure of the gas admitted through the inlet pipe from the main. The pointer indicates upon the dial pressures in hundredths of an inch up to 1½in. With the exception of the "jet," the contrivance is simply a King's gauge, having a delicate regulating cock, and a water-line regulator.

The following directions are given for its adjustment and use:—In fixing the instrument, care must be taken to have it placed perfectly level upon a firm base, so as not to be affected by vibration or other disturbing causes. Fill the tank with water up to the overflow line. Hang on the float so that it falls on the left side of the wheel. Let the balance-weight cord have one turn round the wheel; and it will then hang close up to the wheel on the right side. Hold the wheel with the thumb and finger of one hand, and shift the pointer (which is friction-tight on the shaft) with the other, till it stands at zero, taking care that it works freely. It is necessary once a day to turn off the inlet cock and open the vent cock, in order to ascertain whether the pointer will fall to zero when the pressure is off. If it does not do so, the water-line must be re-adjusted as follows:—

Turn on the cock between the well of the pressure gauge and the brass cylinder fixed on the left-hand side of the instrument, which latter is the water-line regulator. When this cock is open, the water in the cylinder rises to the height of that in the well. A plunger, which nearly fits the cylinder, is attached to the cover of the latter by means of a fine-screwed piston-rod terminating in a milled head. If it is made to descend into the water, it causes a displacement equal to the bulk of that portion which is forced below the water-line; and the water displaced passes into the well of the pressure gauge, moving the pointer in the direction above zero. If, on the other hand, the plunger is raised out of the water in the cylinder, the bulk withdrawn is immediately replaced by water from the well of the pressure gauge, and the pointer is moved in the direction of zero.

As a modification of the jet photometer, Messrs. W. Parkinson and Co. make a self-registering photographic jet photometer devised by Messrs. Gibbons and McEwens.

The apparatus (Fig. 20) consists of an ebonised case of well-seasoned pinewood. The compartment where the jet burner is fixed is lined with tin, and stained black. There are four doors, one to each compartment, made of walnut, with patent catches, the top doors being fitted with plate glass and the bottom with ruby glass, the latter to cut off any actinic rays from entering the case.

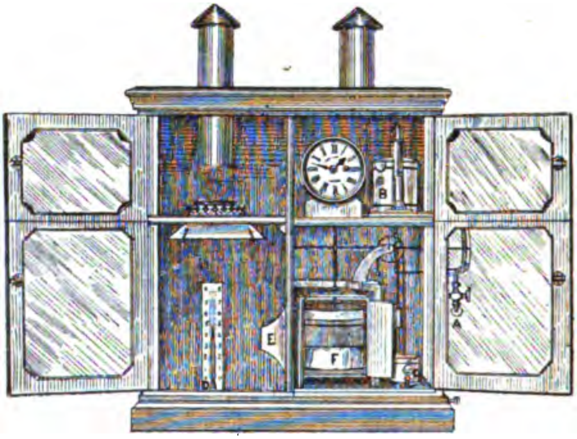

Fig. 20.

The gas to be tested is brought in at cock A, and taken to experimental governor B, from there to the King's gauge C, which indicates pressure on the scale at the side of the case in tenths of an inch; then from King's gauge the gas is taken to the jet burner D, behind which is placed a pair of graduated glass scales divided into inches and tenths, the length of flame with a standard quality of gas being limited to about 5in. in height.

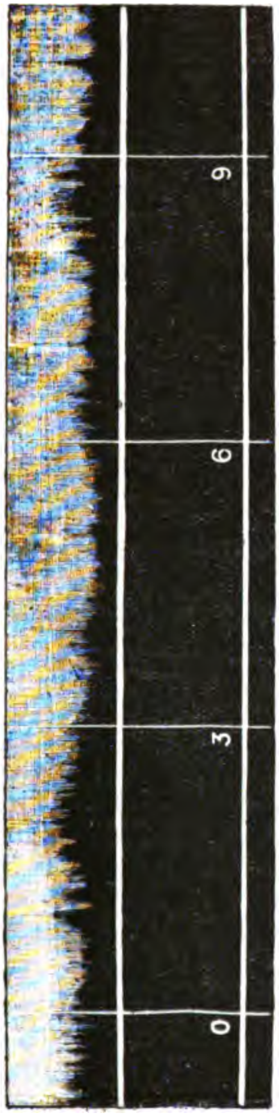

Fig. 21.

Horizontal Lines Denoting Illuminating Power and Pressure Line. Vertical Lines Denoting Periods of 3 Hours.

The light from the flame passes through a small slot in the camera bracket E, which acts as a lens and inverts the image of the flame upon the drum F, round which is stretched a sheet of sensitive bromide paper, which is acted upon by the actinic rays from the gas flame. This drum is enclosed in a light-proof mahogany box, the drum being driven by the clock situated above it, once round in twenty-four hours, exposing about ¾in. surface of paper per hour.

The instrument is designed to photograph continuously the height of a coal-gas flame, and to record it upon sensitised paper, which record can be kept for future reference as to the actual illuminating power of the gas delivered at any date, time, or place. It will also be found most useful to gas engineers during the coal-testing periods, when records of the quality of the gas given by various samples of either coal or cannel may be taken, compared, and filed. Records may be taken periodically in order to see that the contractor is maintaining the quality of supplies equal to that of his sample.

There is an adjusting wire in front of the drum which defines upon the paper by a white line the illuminating power of the gas which is required to be made (this line being adjusted by an ordinary bar photometer), and if the gas be of higher or lower illuminating power, as indicated by the lengthening or shortening of the flame, it will record itself over or under the illuminating power line, as the case may be. To make sure that the pressure has been constant during the test, a pressure line is recorded along the bottom of the diagram. The paper being developed in the usual way, shows a graphic delineation (Fig. 21) of the quality of gas sent out from the works. The inventors suggest that the print could be produced in case of any dispute with the authorities as to the intensity of illumination.

Sugg's Illuminating Power Meter.—In February, 1876, Mr. Sugg read a paper before the Institution of Civil Engineers on " Estimating the Illuminating Power of Coal

Gas," from which the following description of the illuminating power meter is extracted:—

This instrument was designed by the inventor principally for the purpose of aiding engineers in the examination of coal and other substances suitable for gas-making. It is intended to test the illuminating quality of all gases under similar circumstances, and to show their relative commercial value.

A " London " Argand burner, provided with a cylindrical chimney, is fixed on the top of a pillar screwed on to a hollow rectangular base, which is firmly soldered to the outer case of an experimental meter. This base has no communication with the inside of the meter case. That part of the pillar between the top of the base and the burner forms a cock, the gas-way of which is not drilled in the usual manner, but is slotted across the plug. The sides of the gas-way being parallel to each other, the cock opens when the lever is turned by regular gradations until it is full open. A quadrant, divided into forty-five equal divisions, attached to the cock, enables the operator to regulate the flow of gas to any required rate with precision. Above the quadrant a sighting frame is fixed, having two upright pillars, crossed by a flat bar at one end, and at the opposite end a frame fitted with blue glass. A scratch is made across the glass exactly 3in. above the solid part of the frame. The bottom of the opening, the top of the burner, and the termination of the thick part of the back columns are all on the same level. The scratch on the glass, and the bar which crosses the back pillars, are also on the same level, and parallel to the three lower points just mentioned. By these arrangements the operator is enabled to adjust the height of the flame to the level of the scratch and the back bar.

On the left side of the hollow base on which the pillar stands is a tube which connects this base to the outlet of a double governor, which serves to maintain uniformity of pressure during the time the instrument is in use.

On the right of the hollow base is fixed a two-way cock, with a lever ending in a knob fixed to its plug. The cock is quarter stopped; so that when it is turned in one direction as far as the stop, it is full open, and in communication with the inside of the meter, which is full of measured gas. In this position the measured gas passes through the length of the plug of the cock, and by means of a tube fixed to the end of the cock at one end, and to the inlet of the double governor at the other, it finds its way through the governor to the hollow base, and finally to the burner. While the gas is passing to the burner by this route, the measuring drum of the meter revolves; but if the lever of the cock is turned in the opposite direction until it meets the stop, another route is opened for the passage of the gas. Now it proceeds directly from the inlet of the meter without passing into the measuring drum, through the length of the plug of the cock, and out by the same tube as before to the inlet of the governor, thence to find its way to the hollow base and the burner. In this position of the lever the measuring drum of the meter is at rest, and the gas is unmeasured. The governor having been properly adjusted, and the meter having from eight-tenths to ten-tenths of pressure at its inlet, this change in the position of the lever will not influence the height of the flame. The index hand is attached to the arbor of the measuring drum, and revolves with it; both making a revolution in the same time. The dial is divided into divisions corresponding with the illuminating power, in average parliamentary standard sperm candles, of the different qualities of gas which will give a flame of 3in. in height. Thus, if the meter is supplied with 16-candle gas, and the flame is maintained at 3in., the index hand will make one complete revolution in one minute. If the meter is supplied with 12-candle gas, and the flame is maintained at the 3in. line, the hand will make one revolution and a part of another, arriving at the figure 12 in one minute. With 20-candle gas it will make less than a complete revolution in one minute, and arrive at 20. The instrument is provided with a minute clock with one pointer hand, which makes a complete circuit of the small dial in one minute. This dial is divided into 60 equal divisions representing seconds.

On the right of the cylinder which forms the outside case of the meter is the water-line gauge, fitted with back and front glasses. At the correct water-line these glasses are scratched across. On the top of the water gauge is a large nut, which can be unscrewed when it is required to fill the meter or clean the gauge glasses. The plug at the lower part of the gauge is for the purpose of running out the water when there is too much in the meter.

The mode of making a test is very simple. Turn the lever so as to make the gas pass through the measuring drum, and let it get rid of all air or other kinds of gas in it. Light the burner and adjust the flame to 3in. in height. Then, when the large hand arrives at 16, change the position of the lever, so as to make the gas pass to the burner without going through the measuring drum. The large hand will then stop at 16. Wind up the clock by means of the *remontoir* on the top of the meter just in rear of the dial ring. Start the clock by moving the slide, which is on the left of the meter, close to the governor. Then, when the hand of the clock is passing any one of the divisions of the minute, change the position of the lever of the bye-pass, so as to make the gas pass through the meter. When the minute hand has made one complete revolution, stop the meter by means of the lever, in the manner before described, and read off the illuminating power. The minute clock should not be stopped either before or after the observation, unless it is desired to put the clock entirely at rest.

CHAPTER VI.

PHYSICAL PROPERTIES OF COAL GAS.

THE term "gas" is a generic one, embracing all those substances which have uniform characteristics, viz., invisibility, impalpability, compressibility. They are capable of almost indefinite expansion and compression, under which they become first liquid and then solid. Steam is an admirable example of a gaseous body. At a temperature above 212° F., it is an invisible, elastic substance. When cooled below 212° F., it becomes liquid, and is then known as water. At a temperature below 32° F., it becomes solid, or ice. The physical difference between coal gas and steam is that these temperature boundaries, as we may call them, are far wider removed from one another in the case of coal gas than they are in the case of steam; and, moreover, instead of being a comparatively simple molecular body composed of only two groups of elements, viz., hydrogen and oxygen, as in the case of steam, coal gas is a highly complex mixture of chemical combinations of those two elements, together with carbon in considerable abundance, and a little nitrogen and sulphur.

Passing over the question of chemical composition for the moment, the point of immediate importance for consideration is that of *diffusion*, as upon this principle depends much of the work done in regard to the utilisation of coal gas.

Solid substances when mixed together and left under ordinary circumstances, will remain in the condition in which they are left, but certain liquids—water and turpentine, for instance—will rapidly separate into two distinct layers, that having the greatest density being at the bottom. Other substances, such as water and alcohol, if gently poured into the same vessel, will gradually combine into one with no line of demarcation between them. This act of combination is known as diffusion. The way in which atmospheric air is diffused or dissolved in water which has been boiled and cooled out of contact with air, affords a striking example of the manner in which diffusion takes place. By the following method this action may be watched in the most charming manner. If a jar of water be treated with a few drops of a strong solution of the true hyposulphite of soda (not the common "hypo" of the photographer), the oxygen dissolved in the water will be rapidly absorbed; the point at which it disappears is easily discernible by adding a few drops of a solution of sulphindigotic acid which, when the oxygen is present, will impart a blue colour to the water. When the oxygen is all absorbed the blue colour is changed to a pale yellowish tint. If the neutral point is exactly hit, showing that all the oxygen dissolved in the water has been absorbed by the hyposulphite, the re-absorption of fresh quantities of oxygen will immediately become visible by its action in re-oxidising the indigo solution, which will be seen to gradually change throughout the depth of the liquid as the oxygen diffuses into and through the water. This experiment is very striking. The effect can be repeated again and again by adding fresh quantities of the hyposulphite in quantity just sufficient to discharge the blue colour of the indigo. There are various other ways of demonstrating the same action, but few, if any, better than the foregoing. The water should be perfectly still at the time of the experiment in order that it may be seen that the diffusion is purely due to molecular action, and not to any ordinary process of mixing.

Just as the gaseous oxygen diffuses into water, so will it diffuse into another gas whenever the opportunity presents itself; and in like manner any two gases when brought into contact will more or less rapidly diffuse one into the other, and thus form a combined medium in which the component elements are equally distributed throughout. The degree of rapidity of this diffusion will depend upon the specific gravity of the gas in question. *"All gases, according to the kinetic theory, are composed of molecules in rapid motion, which have been compared to elastic balls, which lose no energy when they come into collision; and hence, as these collisions occur at infinitely minute intervals, there is a constantly varying alteration of velocity in direction and magnitude." "Thus the velocity of a molecule is made up of two factors; one, called the velocity of the medium, is the same for all the molecules, while the other, called the velocity of agitation, is irregular both in magnitude and direction." "The result of this motion is, that if in any part of the medium the molecules are more numerous than in a neighbouring region, more molecules will pass from the first region to the second than in the first direction; and for this reason the density of the gas will tend to become equal in all parts of the vessel containing it, except in so far as the molecules may be crowded towards one direction by the action of an external force, such as gravity. Since the motion of the molecules is very swift, the process of equalisation of density in a gas is a very rapid one, its velocity of propagation through the gas being that of sound." "Let us now consider two gases in the same vessel, the proportion of gases being different in the different parts of the vessel, but the pressure being everywhere the same. The agitation of the molecules will still cause more molecules of the first gas to pass from places where that gas is dense to places where it is rare, than in the opposite direction; but since the second gas is dense, where the first one is rare, its molecules will be, for the most part, travelling in the opposite direction. Hence the molecules of the two gases will encounter each other, and every encounter will act as a check to the process of

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* "Ency, Britt.," vol. vii., page 215.

equalisation of the density of each gas throughout the mixture."

"The interdiffusion of two gases in a vessel is, therefore, a much slower process than that by which the density of a single gas becomes equalised, though it appears from the theory that the final result is the same, and that each gas is distributed through the vessel in precisely the same way as if no other gas had been present, and this even when we take into account the effect of gravity."

"The values of the coefficients of several pairs of gases have been determined by Loschmidt.[†] They are referred in the following Table V. to the centimetre and the second as units, for the temperature 0° C. and the pressure of 760 ~~centi~~metres of mercury :—

milli

TABLE V.

	D.
Carbonic acid and nitrous oxide	0·0983
„ „ carbonic oxide	0·1406
„ „ oxygen	0·1409
„ „ air	0·1423
„ „ marsh gas	0·1586
Carbonic oxide and oxygen	0·1802
Sulphurous acid and hydrogen	0·4800
Carbonic acid and hydrogen	0·5558
Carbonic oxide and hydrogen	0·6422
Oxygen and hydrogen	0·7214

The specific gravity (air = 1) of these various gases are as follows :—

TABLE VI.

Carbonic acid	1·529	Nitrous oxide	1·527
„	1·529	Carbonic oxide	0·967
„	1·529	Oxygen...	1·108
„	1·529	Air...	1·000
„	1·529	Marsh gas	0·550
Carbonic oxide	0·967	Oxygen...	1·108
Sulphurous acid	2·247	Hydrogen	0·069
Carbonic acid	1·529	„	0·069
Carbonic oxide	0·967	„	0·069
Oxygen...	1·108	„	0·069

[†] Imperial Academy of Vienna, March 10th, 1870.

From this it will be seen that the diffusion takes place at very unequal rates. This is in consequence of the fact that the rate of diffusion of gases varies inversely as the square roots of their densities. Hydrogen, therefore, having a density of 0·069, will diffuse four times as rapidly as oxygen, which has a density of sixteen times that of hydrogen.

In order to clear the way for another consideration in respect to the action of burners it is desirable to consider the action which takes place when a jet of gas is sent under pressure into an atmosphere of another gas at a less pressure. For this purpose we may turn to the principle of the Giffard's injector, so generally used for feeding steam boilers. In this contrivance steam blows through an annular orifice which can be regulated in size, and as it meets the feed-water is condensed, producing a vacuum and causing the water to rush in with great velocity, and to stream down the combined nozzle of the injector, its velocity being accelerated by the pressure of the steam on the back of the nozzle. In the lower part of the combined nozzle the steam expands and loses velocity, which is compensated for by an increase in pressure on hydro-dynamic principles Although not strictly the same in action, yet the manner in which a jet of gas behaves is somewhat comparable to that of the steam. There is a rush of gas through an opening under pressure; this rush induces a current of air to join that of the gas, and, according to the density of the gas, the size of the opening and the pressure exerted, so will the flame produced by the jet of gas, if ignited, yield more or less light. Broadly stated, we may say, "Rich gas, small orifice, and high pressure; poor gas, large orifice, and low pressure." For instance, with a rich gas we require an ample supply of oxygen. This is obtained by sending the gas through a small orifice at a high pressure, with the result that a larger proportion of oxygen is drawn into the flame than would otherwise be the case, and a good, well-burning flame is obtained instead of an unsteady, smoky flame which does not develop the full lighting value of the gas.

From a consideration of the diffusive powers of gases it will be seen that those gases which are lightest in specific gravity will pass through a given-sized aperture at a greater rate than those of heavier gravity. Therefore, in selecting a particular burner for any special gas, we should have regard to all these considerations. Roughly speaking, coal gas is composed of about 50 per cent. of hydrogen and 40 per cent. of marsh gas. From the foregoing Tables V. and VI. it will be seen that the specific gravity of hydrogen (air = 1) is 0·069, whilst that of marsh gas is 0·550. As the diffusive powers vary inversely as the square roots of their densities, the diffusive power of marsh gas is, therefore, 2·85 to 1 of hydrogen. Therefore hydrogen will diffuse nearly three times as fast as marsh gas, variations in the relative proportions of either of these ingredients, or undue proportions of carbonic oxide, having only a diffusive power of 3·8, or worse still, of an excessive quantity of carbonic acid, having a diffusive power of 4·7 to that of 1 of hydrogen, will most seriously affect the rate of consumption under given conditions of pressure and aperture, and consequently the rate of oxidation and resulting illumination afforded.

From these considerations it will be seen that, apart from the important question of the chemical quality of the gas, the choice of the most suitable burner must depend upon the four functions referred to above—viz., the specific gravity of the gas, the pressure at which it is supplied, the size of the orifice through which it is forced for ignition, and the quantity of air induced by the jet so formed. The multiplication of these jets does not affect the question, except in so far that by the heat radiated from each of the several flames, the energy of combustion of its neighbours may be accelerated.

The cause of the luminosity of flame has been a question much discussed, and it will not be here out of place to consider some of the main points at issue.

In 1817 Sir Humphry Davy assumed that the cause of luminosity in flames was the incandescence of solid particles of carbon at the moment of their liberation from chemical combination. This theory held its own for many years, and seemed to gather no little force from the results of experiments by the author on the variation in the luminous energy emitted from flat flame burners in different directions, and by the further fact that the denser the character of the flames tested the more marked became the reduction in the intensity of the light emitted from the edge of the flame. For instance, when an ordinary flat-flame burner was tested in all azimuths, it was found that the light emitted from the edge of the flame was less than that from the flat side by some 10 to 20 per cent., and that when a dense flat flame—viz., that produced from an albo-carbon burner—was tested, the light from the edge of the flame fell off by about 37 per cent. The inference to be drawn from these and many similar experiments has been held to support the theory of Sir Humphry Davy. In 1868, however, the late Sir Edward Frankland showed that by pressure, non-luminous flames might be made luminous. It has also been shown that luminosity is largely influenced by temperature, a fact which has been largely made use of in connection with the recuperative burners first introduced by Herr F. Siemens.

CHAPTER VII.

CHEMICAL COMPOSITION OF COAL-GAS.

As may be expected from a consideration of the fact that almost every parcel of coal delivered to a gasworks must necessarily have slight differences in quality, so will the resulting quality of the gas made therefrom vary, especially when we take into account the different methods of manufacture, temperature of retorts, degrees of exhaust, &c.

Ordinary 16 to 17 candle normal coal-gas may be roughly taken as consisting of :—

Hydrogen	51·0
Marsh gas	37·0
Illuminants	6·0
Carbon monoxide	5·0
Carbon dioxide	0·0
Nitrogen	0·8
Oxygen...	0·2
	100·0

As stated above, the quality of the gas will vary with the method of manufacture. This is well illustrated by the following results, obtained by Mr. Lewis T. Wright, and published by him in the *Journal* of the Chemical Society (1884, page 99), to which the author has added a column showing the value of the gas in each case, in terms of "pounds of sperm per ton of coal" for better comparison.

In each case equal quantities of the same coal were distilled under like circumstances, with the sole difference of temperature as shown in the Table VII.

TABLE VII.

No. of experiment.	Temperature.	Gas made per ton.	Illuminating power of gas in candles.	Total "candles per ton."	Pounds of sperm per ton.	Chemical composition of gas. Per cent. Hydrogen.	Marsh gas.	Olefines.	Carbon monoxide.	Nitrogen.
I.	Dull red ...	8,250	20·5	33,950	580	38·09	42·72	7·55	8·72	2·92
II.	Hotter	9,693	17·8	34,510	592	43·77	34·50	5·83	12·50	3·40
III.	Hotter	10,821	16·7	36,140	620	lost	lost	lost	lost	lost
IV.	Bright orange	12,006	15·6	37,460	642	48·02	30·70	4·51	13·96	2·81

Hunt* has carried this point a step further, and has shown that the higher the temperature employed in carbonising up to a certain point the greater the value of the gas produced, a result no doubt largely due to a portion of the tar being gasified. Upon further increase in the temperature a decrease in the value of the gas made per ton occurs as follows:—

TABLE VIII.

Temperature. F.	C.	Cubic feet of gas per ton.	Ill. power.	Candles per ton.	Pounds of sperm per ton.
1400	760	9,955	18·36	36,555	623
1520	827	11,179	18·00	40,248	690
1600	871	12,977	17·79	42,968	737
1740	949	12,015	16·82	42,155	723
1885	1002	14,149	14·28	40,412	698

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* See Hunt on "Gas Lighting—Chemical Technology" (Churchill), pages 20 and 21.

This agrees with the following results obtained by the author, viz.:—

TABLE IX.

Temperature.		Cubic feet per ton.	Illuminating power.	Candles per ton.	Pounds of sperm per ton.
F.	C.				
1382	750°	8,700	16·50	28,710	492
1517	825°	10,835	15·04	32,592	559
1607	875°	11,968	14·80	35,481	608

According to M. Princep:—

Red heat = 649° C. = 1200° F.
Orange heat = 899° C. = 1650° F.

From these results it will be seen how important it is to carefully consider all the data in regard to the gas-making qualities of coal. The value of the tar, ammoniacal liquor, and coke obtained must also be taken into consideration, but in respect to the scope of the present work these need not be now further considered.

It may be useful to the non-technical reader to mention how the factors *candles per ton* and *pounds of sperm per ton* are arrived at.

The standard rate at which the gas is consumed when being tested for its illuminating power is 5 cubic feet per hour. Therefore, the volume of gas made per ton is divided by 5 to ascertain the number of hours during which the given quantity of gas would continue to give its standard light. If this be equal to, say, 16·5 candles, each burning spermaceti at the parliamentary rate of 120 grains per hour, then one-fifth of the quantity of gas made per ton of coal multiplied by its illuminating power will equal the "candles per ton." On multiplying this factor by 120 and dividing by 7000 the "pounds of sperm per ton" are found.

Shortly :—

Candles per ton = $\frac{\text{make}}{5}$ × illuminating power.

Pounds of sperm per ton = illuminating power × make × 0·00848.

Coals of low grade will yield	480 lb. of sperm per ton.
„ average „ „	530 „ „ „
„ high „ „	560 „ „ „

at normal working temperatures.

Table X., which has been compiled for the purpose of the present work by Mr. H. Leicester Greville, F.I.C., chemist to the Commercial Gas Company, shows the differences in the quality of a gas by reason of the processes of purification which it undergoes between its evolution from the coal in the retort to the time of its delivery to the consumer.

TABLE X.

Constituent.	Crude.	Outlet of scrubber.	Outlet of Iron P.	Outlet of Lime P.
Hydrogen	47·5	48·5	48·8	49·8
Marsh gas	35·5	36·3	36·5	36·9
Heavy hydrocarbons ...	4·3	4·0	4·0	4·0
Carbon dioxide	1·4	1·0	1·0	nil
Hydrogen sulphide ...	1·6	0·5	nil	nil
Nitrogen	3·0	3·0	3·0	3·0
Ammonia	0·7	nil	nil	nil
Carbon monoxide ...	6·0	6·1	6·1	6·2
	100·0	99·4	99·4	99·4

By this we see that the process of purification has removed the ammonia, sulphuretted hydrogen, and the carbonic acid.

It will be noticed that in all the foregoing analyses we have certain factors referred to indifferently as "Illuminants," "Olefines," and "Heavy Hydrocarbons." The student will naturally wonder and ask the reason of this. The answer is that the methods of gas analyses were and are very indefinite as regards the estimation of the illuminating constituents. After numerous researches, Prof. Lewes gave the following as an approximation of the percentage of the various illuminants in a sample of South Metropolitan gas.

The *total* of the illuminants is stated to be accurate, and it is claimed that their rough sub-division gives a far clearer insight into the character of the gas than hitherto[*] :—

	Hydrogen		47·9	
Illuminants	Ethylene series	approx.	3·5	Total hydrocarbons, 45·6 per cent.
	Benzene series	approx.	0·9	
	Methane series	by paraffin	7·9	
		by explosion	33·3	
	Carbon monoxide		6·0	
	Carbon dioxide		0·0	
	Oxygen		0·5	
	Nitrogen		0·0	
			100·0	

The student will again probably inquire as to which of these substances the illuminative effect of coal-gas is due.

This has been answered by the researches of Frankland and Thorne, Kimblach, and others, which may be summarised in the following Table XI.:—

TABLE XI.—*Illuminating Value of Hydrocarbons per five cubic feet of gas.*

Methane	5·2	candles.
Ethane	35·7	,,
Propane	56·7	,,
Ethylene	70·0	,,
Benzene	420·0	,,
Toluene	741·7	,,
Naphthalene	990·9	,,

The effect of diluting ethylene, as a representative of the illuminating constituents in coal-gas, with various other gases, has been studied by Dr. Percy Frankland, who obtained the following results[*] :—

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[*] Lewes, Society of Arts, December 1st, 1890.

TABLE XII.—*Combustible Diluents.*

Diluent.	Percentage ethylene.	Percentage diluent.	Candle-power of mixed gas per 5 cubic feet per hour.
Hydrogen	77·55	22·45	54·58
	68·39	31·61	49·37
	53·58	46·42	39·21
	35·47	64·53	30·85
	26·08	73·92	22·84
	13·37	86·63	6·73
	10·00	90·00	0·00
Carbon monoxide	81·65	18·35	55·27
	67·75	32·25	47·73
	46·30	53·70	33·09
	37·94	62·06	26·52
	28·73	71·27	13·26
	23·89	76·11	6·56
	20·00	80·00	0·00
Methane	85·67	14·33	57·91
	69·09	30·91	47·88
	57·74	42·26	40·42
	35·90	64·10	33·17
	13·00	87·00	19·35
	7·87	92·13	17·59

As ethylene, by the previous Table XI., had an initial illuminative value of 70 candles, it will be seen by the above how this quality is affected by different degrees of dilution with gases which in themselves are combustible, but capable of affording practically no illumination under ordinary conditions.

Methven showed[†] in 1889 that candles burning in the ordinary atmosphere, when the temperature from day to day was practically constant throughout the experiments, possessed a light value of 1·104 candles, compared with a light of constant power, per 120 grains consumed, which was increased when they were burnt in a dry atmosphere to 1·196 candles per 120 grains, or an increase of 8·38 per cent. Continuing these researches on the influence of aqueous vapour on flames from different burners, Methven observed that when dried air is supplied to the flame the light therefrom is practically of constant quality; but when saturated air is supplied, with increasing temperature, the light value is rapidly diminished. Thus, between

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[*] *Journal* of the Society of Chemical Industry, vol. iii., page 275.

[†] "Photometry," by J. Methven, Southern District Association of Gas Engineers and Managers, November 14th, 1889.

TABLE XIII.—*Non-combustible Diluents.*

Diluent.	Percentage of ethylene.	Percentage of diluent.	Candle-power per 5 cubic feet of gas.
Carbon-dioxide ...	93·68	6·32	55·52
	90·59	9·41	51·81
	89·03	10·97	49·98
	81·73	18·27	42·81
	70·75	29·25	33·23
	64·14	35·85	26·52
	52·94	47·06	14·72
	45·61	54·39	7·49
	40·00	60·00	0·00
Nitrogen	84·69	15·31	51·96
	71·12	28·88	39·58
	59·93	40·07	29·64
	47·08	52·92	20·81
	36·24	63·76	11·82
	28·81	71·19	7·20
Oxygen...	82·57	17·43	70·93
	80·67	19·33	72·53
	75·51	24·49	74·19
	68·50	31·50	71·17
	60·69	39·51	Explosion
Air...	79·68	20·32	54·45
	67·15	32·85	45·84
	55·92	44·08	37·16
	42·69	57·31	26·78
	33·91	66·09	16·22
	22·31	77·69	0·61
	13·31	86·69	Explosion

the temperatures of 50° and 75° F. a loss of 10 per cent. of light value from the 5ft. flame results.

Coal-gas contains normally about 2 per cent. of moisture, which reduces the illuminating power of the dry gas to the extent of 3·3 per cent.

Wurtz carried out a series of experiments to ascertain the effect of the addition of air to coal-gas with the following results :—

TABLE XIV.

Air added.	Percentage loss of light.
3·00	15·69
4·96	23·83
11·71	41·46
16·18	57·53
25·00	84·00

According to Professor Lewes,* the addition of oxygen to gases rich in hydrocarbons causes an increase in the illuminating power up to a certain point. The temperature of the flame is increased by burning up the hydrogen of the hydrocarbons, and rendering the carbon incandescent without diluting the flame with nitrogen to the extent which would have been necessary had air been used for the purpose.

TABLE XV.

Volume taken.		Temperature, ° C.		
Gas.	Diluent.	Air.	Nitrogen.	Carbon dioxide.
1 vol.	1 vol.	—	1180	1100
1 „	2 „	1260	1150	880
1 „	3 „	1116	1040	780

The effect of such gas as hydrogen, marsh gas, and carbon monoxide, is simply to dilute the flame, and, by separating the molecules of the hydrocarbons, to make them more difficult to decompose; whilst such bodies as the carbon dioxide, nitrogen, air, and water vapour, not only dilute, but also cool the flame (Table XV.), as they do not add to the heat by any action of their own, and have to be heated up to the same temperature as the flame itself.

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* Cantor Lectures, 1890.

Rosette determined the temperature of a gas flame diluted with air, nitrogen, and carbon dioxide respectively, and found that it was least with the carbon dioxide and highest with air, a result which agrees with Dr. Frankland's determination of illuminating power.

CHAPTER VIII.

ENRICHMENT.

It has been contended that the cheapest gas is by no means always the most economical when used in flat-flame burners, although the case is doubtless different when the incandescent mantles are employed.

This point was clearly brought out in connection with an experiment made in London in consequence of a suggestion that the effect of the enrichment of the gas was only a useless expense, and that if stopped, the consumer would not know the difference, and that there would be no complaints. During this experiment, viz., from April 24th to May 5th, 1894, the gas was tested as usual at the official stations, and also by means of the portable photometer, both at the stations and in the districts away from the fixed stations, with the result that the quality of the gas was found to be fairly uniform, viz, 15·0 candles. The experiment of supplying unenriched gas being concluded, carburetting was again resorted to, and the series of tests repeated in the same order and places under precisely the same conditions, with the result that the quality of the gas in the districts was found to be 14·85 candles, and that at the official fixed stations 16·5 candles.

From this it became clear that as the former set of testings, made when the gas was supplied uncarburetted, indicated a fairly uniform supply, so these later tests made after the resumption of the carburetting process most clearly demonstrate that the effect of that process is limited in its operation to the official testing place and its near proximity. This result fully explained any failure on the part of the consumers to detect any difference in the quality of the gas supplied to them during the two weeks of the experiment.

These facts made more fully evident the necessity for maintaining the prescribed quality of the gas throughout the whole of the districts. For the purpose of elucidating the fact more clearly, the writer made a careful series of experiments to determine the quantity of gas of different illuminating powers required to produce a uniform light when consumed in either of two of the most generally employed forms of burners, and these results were given in the report previously referred to, from which the following Table XVI. is taken:—

TABLE XVI.

Corrected value of the gas in terms of legal candles.	Cubic feet of gas required to yield 11·87 candles of light from	
	"Batswing."	"Fishtail."
13·6 to 13·9	5·48	6·33
14·0 to 14·5	5·95	6·20
14·6 to 14·9	4·75	5·59
15·0 to 15·5	4·75	5·70
15·6 to 16·0	4.40	4·86
Over 16·0	4·00	4·64

From these results it appears that in order to obtain the same quantity of light from a "batswing" burner consuming 14·0 candle gas as would be obtained with 16·0 candle gas, about 5·95 cubic feet per hour must be consumed instead of 4·4 cubic feet, or 35 per cent. more; with 15·0 candle gas instead of 16·0, the increase is from 4·0 to about 4¾, or 18 per cent.

With a "fishtail" burner the increase in the quantity of gas, when 14·0 candle gas is employed is about 33 per cent., and when 15·0 candle gas is used, about 18 per cent.

According to this comparison, the consumer who used either of these burners would have to pay 18 per cent. more for his gas to obtain equal intensity of light, in the event of the quality being lowered from 16·0 to 15·0 candles. The ratios will be varied considerably with different burners and qualities of gas, but the chief feature will remain.

The summarised conclusions of the experiments were as follows:—

(1) That the effect of the present system of enrichment is partial, and in proximity to the stations.

(2) That the effect of a reduction in the quality of the gas is equal to a far larger increase in the quantity required for unit light than is compensated for by a reduction in price.

(3) That the testings by the portable photometer are absolutely reliable.

The facts thus brought out by the investigation cannot fail to be of assistance in similar instances, and point to the absolute fallacy of any conclusions as to the fairness or otherwise of the price of gas, which do not at the same time take into account the whole question of quality, not merely in regard to what is euphemistically termed the "statutory power," but to the actual and real power for lighting purposes of the gas supplied to the consumers, according to the burner which is used.

This point was more clearly brought out in the following account of experiments submitted by the author to the Society of Chemical Industry in December, 1900:—

The use of coal gas purely as a heating agent raises another point entirely apart from that of the illuminating effect when the gas is burnt in those burners commonly employed. The question is also complicated by the recent introduction of the incandescent gas burners, or "mantles," which materially affect the question so far as the number employed bears any ratio to the total number of burners of all kinds in general use, If none but incandescent burners were employed, then it might be granted at once that the old idea of "illuminating power" of coal gas must be very largely and seriously modified—so much so that the expression "heating power" might safely be used in its place. As long, however, as the great proportion of the gas is consumed in ordinary luminous flame burners, it must be admitted that there is no excuse for neglecting the effect of variations in quality upon the quantity of gas required to give normal or "unit" illumination.

If the quantity of gas required to be burnt to afford any desired degree of illumination be a variable factor, in consequence of fluctuation in quality, and the gas so employed be charged for at a uniform rate for each cubic foot used, the actual cost of that degree of illumination must vary with the quantity. Thus, a gas of higher price, but of higher quality, may be far cheaper to the consumer than is a gas of lower price but lower quality. These two factors must be taken together, and, in order to obtain a proper estimate of their ratios, the conditions under which the gas is to be consumed must first be determined, as these conditions will materially affect the problem. Taking the extremes, for instance, the value may depend upon quantity only if the basis be that of the incandescent burner, but even then the heating value of the gas should be taken into account. On the other hand, if the basis be that of a flat-flame burner, then the value must depend upon illuminative effect as well as on the quantity required to be consumed.

These considerations have rendered it necessary that the effect of consuming gases of different qualities in those burners commonly employed, as well as in the standard Argand and incandescent burners, should be clearly established. To assist in this the author has conducted a number of tests with various burners and different qualities of gas in regard to the quantity required to yield the maximum or "normal" light from any given burner when burning 16·0 candle gas under the most suitable conditions.

After a preliminary series of experiments of a necessarily limited character, the author arranged six series of photometrical tests. The first of these was made with coal-gas at Widnes; the second with gas supplied by the Gas Light and Coke Company; the third with gas supplied by the South Metropolitan Gas Company; and the fourth, fifth, and sixth with coal and water gases in various proportions.

For the purpose of the first series of experiments, Mr. Carr, the manager of the Widnes Corporation Gasworks, kindly prepared different qualities of gas from time to time and stored them in an experimental 100ft. holder, which was connected to the author's photometer. The procedure was to first carefully test the quality of the gas when burnt at the rate of 5 cubic feet per hour in a No. 1 London Argand burner, or what is commonly called its "illuminating power," and then to burn it in various gas burners in succession, making photometrical determinations of the light and estimations of the quantity of gas consumed.

The first series of tests was made with gas which had an illuminating power of 16·2 candles when burnt at the rate of 5 cubic feet per hour in the standard Argand burner. This value was ascertained by independent tests by different observers using two different photometers, viz., the closed Evans photometer on the works, using candles as a standard, and the author's portable bar photometer, using the Dibdin 10-candle Pentane Argand standard, as recommended by the Board of Trade Committee. The value of the gas being thus ascertained, the standard London Argand burner on the portable photometer was removed and a Sugg's "table-top' burner No. 4 placed in position, and the gas adjusted until a fair and even-burning flame was obtained, which was found to be equal to 14·4 candles. The quantity of gas consumed was then ascertained by means of the experimental meter, which was found to indicate a rate of 5·3 cubic feet per hour,

TABLE XVII.—WIDNES SERIES.—*Table showing the Variation in Quantity of Gas consumed to yield Unit Light for each Burner when varying Qualities of Gas are used.*

No.	Burners.	Illuminating power.	Consumption of gas per hour with							
			11·2	12·2	13·5	14·2	15·2	16·2	17·2	19·2
			Candle gas.							
1	Standard Argand...	16·0	6·25	6·0	5·7	5·4	5·15	4·95	5·0	4·7
2	Sugg's table top, No. 4	14·4	11·2	9·7	7·75	6·4	6·1	5·3	4·5	3·9
3	" " No. 5	15·3	9·5	7·8	6·2	5·7	5·5	5·35	4·6	4·15
4	" " No. 6	17·0	10·4	8·9	7·3	6·9	6·3	5·65	4·8	4·5
5	" " No. 7	24·6	13·1	11·4	9·2	9·4	8·6	7·75	6·7	6·5
6	Sugg's slit union, No. 4	11·7	12·1	9·8	6·2	5·9	5·15	4·5	3·5	3·2
7	" " No. 5	15·3	9·8	8·8	7·1	6·7	6·0	5·35	4·4	4·1
8	" " No. 6	20·0	11·4	9·6	8·5	8·0	7·3	6·35	5·8	5·2
9	" " No. 7	18·5	10·6*	8·9	7·4	6·9	6·35	6·0	5·2	4·85
10	Sugg's fishtail, No. 6	14·8	11·2*	9·2*	7·5	6·4	5·8	5·1	4·4	4·0
11	" " No. 7	10·5	11·4*	10·7*	6·0	5·6	4·95	4·2	3·4	2·8
12	Bray's fishtail, No. 4	8·6	15·5*	13·4*	10·5	9·0	5·6	4·3	3·1	2·6
13	" " No. 5	11·8	14·0*	10·6*	9·8	6·8	5·9	5·05	4·0	3·2
14	" " No. 6	12·4	12·6*	10·7*	8·3	6·6	5·8	5·0	4·1	3·4
15	" " No. 7	14·0	9·8*	9·1	8·0	6·0	5·6	5·1	4·15	3·6
16	Bray's batswing, No. 6	16·6	11·6	10·0	9·3	7·0	6·7	5·7	5·1	4·3
17	Bray's union, with Codac economiser	14·6	6·8	6·3	7·1	5·4	5·0	4·95	4·6	4·2
18	Mint's batswing, No. 6	19·0	12·1	10·3	9·2	8·0	7·35	6·6	5·7	4·8
19	" " No. 7	16·8	9·8	9·0	8·3	6·9	6·25	5·55	5·1	4·4
20	Iron fishtail	3·3	(out of range)				5·8*	3·0	1·7	1·4
21	Butcher's burner	26·5	13·7	12·0	11·5	10·5	9·3	8·4	7·9	7·4
22	Imitation Bronner, No. 4	10·1	5·5	4·8	4·5	4·3	3·8	3·5	3·15	2·9
23	Peebles, No. 4	9·0	6·3*	6·2*	5·0*	4·6*	4·05*	3·6	3·1	2·4
24	" No. 5	13·0	7·4*	6·6*	5·6*	5·5*	4·8	4·55	4·1	3·6
25	" No. 6	15·1	8·2*	7·5*	6·6*	6·1*	5·3	5·0	4·6	4·25
26	Sugg's F Argand	20·5	7·7	7·4	7·2	6·6	6·35	6·3	6·15*	6·15*
27	Welsbach C burner and mantle	Max. intensity	4·9	5·4	4·0	3·7	3·5	3·5	4·2	3·4
28	Sunlight	"	5·9	5·8	5·0	5·0	5·0	5·1	5·0	4·6

TABLE XVIII.—WIDNES SERIES.—*Table showing the Percentage Variation in the Quantity of Gas Consumed to yield Unit Light for each Burner when varying Qualities of Gas are used.*

(100 per cent. = that required with 16·2 Candle Gas.)

No.	Burners.	Illuminating power.	Percentage consumption of gas with							
			11·2	12·2	13·5	14·2	15·2	16·2	17·2	19·2
			Candle gas.							
1	Standard Argand	16·0	125	120	114	108	103	100	100	94
2	Sugg's table top, No. 4	14·4	210	183	146	121	115	100	85	73
3	,, ,, No. 5	15·3	178	146	116	107	103	100	86	77
4	,, ,, No. 6	17·0	184	157	129	122	111	100	85	80
5	,, ,, No. 7	24·6	169	147	119	121	116	100	87	84
6	Sugg's slit union, No. 4	11·7	269	218	148	131	114	100	78	71
7	,, ,, No 5	15·8	183	164	133	125	112	100	82	77
8	,, ,, No. 6	20·0	180	151	134	126	115	100	91	82
9	,, ,, No. 7	18·5	177*	148	123	115	106	100	87	81
10	Sugg's fishtail, No. 6	14·3	220*	180*	147	125	114	100	86	78
11	,, ,, No. 7	10·5	272*	255*	143	121	118	100	81	67
12	Bray's fishtail, No. 4	8·6	361*	312*	244	209	130	100	72	60
13	,, ,, No. 5	11·8	277*	210*	194	135	117	100	79	63
14	,, ,, No. 6	12·4	252*	214*	166	132	116	100	82	64
15	,, ,, No. 7	14·0	192*	178	157	118	110	100	81	70
16	Bray's batswing, No. 6	16·6	204	175	163	123	117	100	89	75
17	Bray's union, with Codac economiser	14·6	137	127	143	110	101	100	93	85
18	Mint's batswing, No. 6	19·0	183	164	139	121	111	100	86	73
19	,, ,, No. 7	16·8	177	162	150	124	113	100	92	79
20	Iron fishtail	3·3		(out of	range)		193*	100	57	47
21	Butcher's burner	26·5	168	143	137	125	111	100	94	88
22	Imitation Bronner, No. 4	10·1	157	137	128	123	108	100	90	83
23	Peebles, No. 4	9·0	175*	172*	139*	128*	113*	100	86	67
24	,, No. 5	13·0	163*	145*	123*	121*	105	100	90	79
25	,, No. 6	15·1	164*	150*	132*	122*	106	100	92	85
26	Sugg's F Argand	20·5	122	117	114	105	101	100	98*	98*
27	Welsbach C burner and mantle	Max. intensity	140	154	114	106	100	100	120	97
28	Sunlight	,,	116	114	98	98	98	100	98	90

In like manner twenty-eight burners were tested in succession with the same gas, and the results recorded in the attached Table XVII., in the ninth column, headed "16·2 candles," which refers to the quality of the gas employed in the experiments in question.

On the completion of the tests of all the burners with 16·2 candle gas, the gas unused in the experimental 100ft. holder was again examined to make certain that no change in the illuminating power of the gas had taken place, the remainder displaced and the holder filled up with gas of another quality, when the tests were repeated in a precisely similar manner, the greatest care being taken to ensure that as far as possible the experiments were strictly comparable.

In this way it was ascertained that the flat-flame burner first tested, viz., Sugg's table-top No. 4, which gave 14·4 candles of light with 5·3 cubic feet per hour of 16·2 candle gas, required, to produce the same illumination, 6·1 cubic feet per hour, when the illuminating power of the gas was reduced to 15·2 candles; 6·4 cubic feet with 14·2 candle gas; 7·75 cubic feet with 13·5 candle gas; 9·7 cubic feet per hour with 12·2 candle gas; and 11·2 cubic feet per hour with 11·2 candle gas; whilst when the quality of the gas was raised to 17·2 candles, the consumption required to yield the same unit or normal lighting power of 14·4 candles was reduced to 4·5 cubic feet per hour; and with 19·2 candle gas the consumption was only 3·9 cubic feet per hour.

In like manner the whole of the burners were tested, and the results tabulated as shown. From this table another (Table XVIII.) was prepared, in which all the results are reduced to terms of percentage quantity of gas consumed, on the basis that the 16·2 candle gas was normal, and therefore taken at 100. By this method of comparison the extra quantity of gas required to compensate for defective quality is at once seen; and, in like manner, the reduction in the quantity required to produce unit light as the quality increases.

In certain instances with low-grade gas the burners could not properly consume sufficient gas to give the amount of light afforded when the 16·2 candle gas was employed, and corrections had therefore to be applied. Where this was done the fact is indicated in the tables by an asterisk. Thus, in the case of Sugg's table top burner No. 7, 24·6 candles of light were obtained with gases down to 12·2 candles, but when 11·2 candle gas was used, only 20·2 candles could be obtained instead of 24·6. As the consumption of gas was 10·8 cubic feet per hour, 13·1 cubic feet would have been necessary to yield the 24·6 candles of light. These corrections more particularly apply to burners adapted for very rich gases when employed with low-grade gases. On the basis of a sufficient number of burners being employed to burn the total quantity of gas of a given quality to yield the volume of light required, this method of approximation would probably give slightly too low a result.

The diagram, A (see page 121), shows the effect of any alteration in the quality upon the actual cost of the gas required to produce unit light with certain representative burners.

On the left-hand side of the diagram, the volume of gas is indicated in terms of percentage for the various abscissæ, and on the right-hand side the corresponding increase or decrease in the cost is shown, on the basis that 16·0 candle gas costs 2s. 6d. per 1000 cubic feet. The ordinates indicate the candle-power of gas supplied. The curves represent unit or normal intensity of the light yielded by the respective burners when burning 16·2 candle gas with a consumption most suited to them, as shown in the third column of Table XVIII.

The bottom curve on the left-hand side of the diagram cuts the ordinate for 19·2 candle gas on the abscissa representing 60 per cent. of the quantity of gas required when 16·2 candle gas is employed. This curve then proceeds upwards until it crosses the ordinate representing

DIAGRAM A.

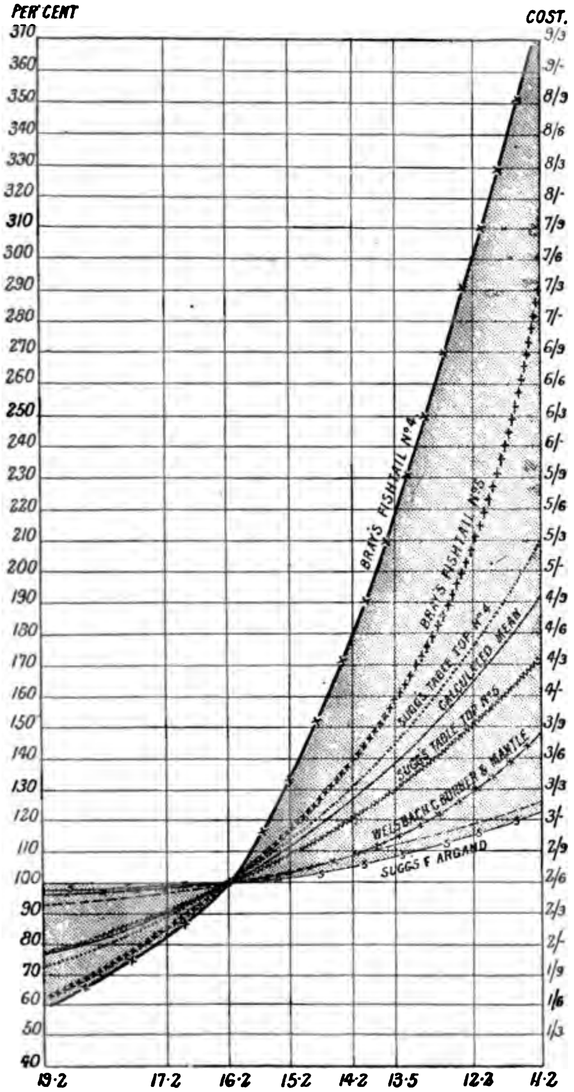

Diagram showing the percentage variation in the quantity of gas consumed to yield unit light for each burner when varying qualities of gas are used.

17·2 candle gas, which cuts the abscissa for 83 per cent. of normal value. The curve then crosses the ordinate for 16·2 candle gas on the abscissa for 100 or normal volume. The curve then proceeds until it cuts the ordinate for 15·2 candle gas on the abscissa for 134 per cent.; and in like manner the ordinate for 14·2 candle gas at 180 per cent.; 13·5 candle gas at 220 per cent.; 12·2 candle gas at 305 per cent.; and the ordinate of 11·2 candle gas at about 380 per cent.

By interpreting the variations in consumption of gas into relative cost, as indicated on the right-hand side of the diagram, it will be seen that in order to obtain equal degrees of illumination with varying qualities of gas, in the case of a No. 4 Bray's burner, the actual cost of the gas to the consumer, on the basis of *light for money*, will be as follows:—

TABLE XIX.

Illuminating power of gas.	Quantity required to give light equal to 1000 cubic feet of 16·0 candle gas.	Actual cost of gas at 2s. 6d. per 1000 cubic feet.	
	Cb. ft.	s.	d.
19·0	600	1	6
18·0	700	1	9
17·0	820	2	1
16·0	1000	2	6
15·0	1340	3	4
14·0	1800	4	6
13·0	2400	6	1
12·0	3040	7	9
11·0	3750	9	6

As it may be thought that No. 4 Bray is an exceptional burner, we may take No. 5 Bray, which may reasonably be looked upon as an average burner generally employed, and ascertain in the above manner the cost of equal light intensity for different qualities of gas (Table XX.).

On this basis it is seen that any variation in price per 1000 cubic feet for each candle alteration in the illuminating power of the gas should be greater than has hitherto been supposed. On the other hand, these facts explain the common complaint as to the otherwise apparently inexplicable rise in the amount of the gas bills—a fall of 2 candles in quality causing a rise, in the case of Bray No. 5 burner, of 44 per cent. on the gas bill; whilst, when the gas is down to 12·6 candles, the amount of the gas bill is doubled. From these facts it will be at once seen that any discussion of the cost of gas per 1000 cubic feet is valueless in the absence of an equal recognition of its *quality*, so far as relates to its use with flat-flame burners.

TABLE XX.

Illuminating power of gas.	Cost of gas per 1000 cubic feet.	
	s.	d.
19·0	1	7
18·0	1	10
17·0	2	1
16·0	2	6
15·0	3	0
14·0	3	7
13·0	4	3
12·0	5	4
11·0	7	1

In the case of the Welsbach and the best Argand burners, which, however, are used to only a very limited extent as compared with the flat-flame burners, the results are less disproportionate, and a moderate reduction in price for each candle-power would not be unreasonable; but, unfortunately, in order to obtain a problematical advantage to the users of gas for heating purposes, those who employ the gas for illuminating purposes in the burners commonly used would suffer to a proportionate extent.

As the foregoing results were obtained with specially prepared gas, it was deemed advisable to repeat the experiments with gas actually supplied to consumers. For this purpose a second series of tests was made in the author's laboratory at Westminster with gas supplied by the Gas Light and Coke Company. In order to obtain gas of very

Table XXI.—*Table showing the Variation in Quantity of Gas consumed to yield Unit Light with each Burner when varying Qualities of Gas are used. Tests made with Gas Light and Coke Company's Gas.*

No.	Burners.	Illuminating power.	Consumption of gas per hour with						Remarks.
			12·0	13·5	14·5	16·0	16·5	19·0	
			Candle gas.						
1	Standard Argand...	16·0	5·3	5·4	5·3	5·0	4·3	3·9	The figures in the column for 16·0 candle gas are calculated from 16·5 c. gas.
2	Sugg's table top, No. 4	14·0	12·9	9·4	9·0	5·2	5·0	3·8	
3	,, ,, No. 5	15·0	10·4	8·0	7·4	4·8	4·7	3·7	
4	,, ,, No. 6	17·0	11·7	8·7	8·6	6·2	6·0	4·2	
5	,, ,, No. 7	24·0	12·5	10·4	8·0	6·8	6·6	5·8	
6	Sugg's slit union, No. 4	12·0	16·3	9·0	9·5	5·5	5·3	3·4	
7	,, ,, No. 5	15·0	12·3	8·4	8·8	5·8	5·6	4·2	
8	,, ,, No. 6	20·0	12·4	9·2	9·1	6·4	6·2	4·8	
9	,, ,, No. 7	18·0	11·1	9·3	9·1	6·0	5·8	4·6	
10	Sugg's fishtail, No. 6	14·0	14·0	8·7	10·5	5·5	5·3	3·8	
11	,, ,, No. 7	10·0	13·2	8·0	8·2	3·8	3·7	3·0	
12	Bray's fishtail, No. 4	8·6	15·1	10·7	10·1	4·7	4·6	3·2	
13	,, ,, No. 5	11·8	14·8	8·8	10·3	5·4	5·2	3·9	
14	,, ,, No. 6	12·4	13·8	10·5	10·2	5·2	5·0	4·1	
15	,, ,, No. 7	14 0	11·9	8·5	8·3	5·0	4·8	3·7	
16	Bray's Batswing, No. 6	17·0	13·0	9·5	10·3	6·2	6·0	4·9	
17	Bray's union, with Codac economiser	15·0	7·8	7·3	6·4	4·7	4·6	4·1	
18	Mint's batswing, No. 6	19·0	14·0	10·8	10·4	6·4	6·2	5·5	
19	,, ,, No. 7	17·0	12·3	8·9	8·4	6·1	5·9	4·7	
20	Iron fishtail	3·0	22·8	12·3	10·0	3·1	3·0	1·9	
21	Butcher's burner	23·0	15·2	11·8	10·8	9·3	9·0	8·3	
22	Imitation Bronner, No. 4	10·0	6·1	5·0	4·8	3·5	3·4	2·8	
23	Peebles, No. 4	9·0	8·3	6·3	6·3	3·5	3·4	3·1	
24	,, No. 5	13·0	9·1	7·2	7·2	4·5	4·4	3·7	
25	,, No. 6	15·0	—	7·6	7·5	5·2	5·0	4·2	
26	Sugg's F Argand	20·0	7·3	7 0	6·8	6·2	6·0	5·4	
27	Welsbach C burner and mantle	Max. intensity	3·3	2·9	3·2	3·4	3·3	2·5	
29	Sugg's gov. burner, table top (0·022)	18·0	—	—	—	5·7	5·5	—	

TABLE XXII.—*Table showing the Percentage Variation in Quantity of Gas consumed to yield Unit Light with each Burner when varying Qualities of Gas are used. Tests made with Gas Light and Coke Company's Gas.* 100 *per cent.* = *that required with* 16·0 *Candle Gas.*

No.	Burners.	Illuminating power.	Consumption of gas per hour with					
			12·0	13·5	14·5	16·0	16·5	19·0
			Candle gas.					
1	Standard Argand	16·0	116	108	106	100	96	78
2	Sugg's table top, No. 4	14·0	248	182	173	100	96	73
3	,, ,, No. 5	15·0	217	166	154	100	98	77
4	,, ,, No. 6	17·0	189	141	138	100	97	68
5	,, ,, No. 7	24·0	184	153	118	100	97	85
6	Sugg's slit union, No. 4	12·0	295	163	178	100	96	62
7	,, ,, No. 5	15·0	212	145	152	100	96	72
8	,, ,, No. 6	20·0	194	144	142	100	97	75
9	,, ,, No. 7	18·0	185	155	152	100	97	77
10	Sugg's fishtail, No. 6	14·0	255	158	191	100	96	69
11	,, No. 7	10·0	348	211	216	100	97	79
12	Bray's fishtail, No. 4	8·6	321	228	215	100	98	68
13	,, No. 5	11·8	274	163	188	100	96	72
14	,, No. 6	12·4	265	202	196	100	96	79
15	,, No. 7	14·0	238	170	166	100	96	74
16	Bray's batswing, No. 6	17·0	210	153	164	100	97	79
17	Bray's union, with Codac economiser	15·0	166	155	132	100	98	87
18	Mint's batswing, No. 6	19·0	219	169	163	100	97	86
19	,, No. 7	17·0	202	146	148	100	97	77
20	Iron fishtail	3·0	735	397	323	100	97	61
21	Butcher's burner	26·0	163	127	116	100	97	89
22	Imitation Bronner, No. 4	10·0	174	143	140	100	97	80
23	Peebles, No. 4	9·0	238	180	180	100	97	89
24	,, No. 5	13·0	202	160	160	100	98	82
25	,, No. 6	15·0	—	146	144	100	96	81
26	Sugg's F Argand	20·0	118	113	110	100	97	87
27	Welsbach C burner and mantle	Max. intensity	97	85	94	100	97	73
29	Sugg's gov. burner, table top (0·022)	18·0	—	—	—	100	96	—

DIAGRAM B.

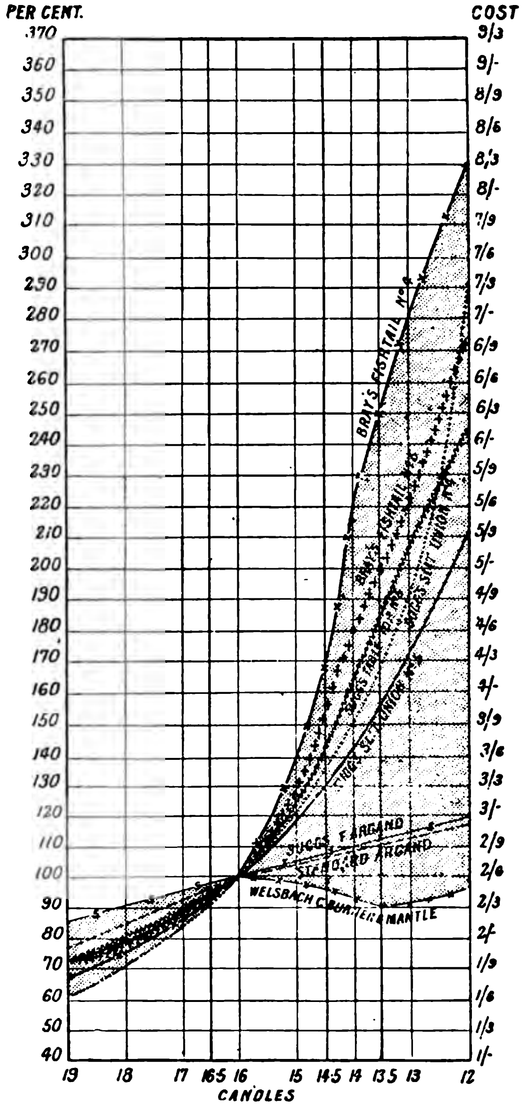

Diagram showing the percentage variation in the quantity of gas consumed to yield unit light for each burner when varying qualities of gas are used. Gas Light and Coke Company's gas. 100 per cent. = that required with 16·0-candle gas.

TABLE XXIII.—*Table showing the Variation in the Quantity of the Gas Consumed to yield Unit Light with each Burner when varying Qualities of Gas are used. Tests made with South Metropolitan Gas Company's Gas.*

No.	Burners.	Illuminating power.	Consumption of gas per hour with					
			12·5	14·5	16·0	16·5	17·2	18·0
			Candle gas.					
1	Standard Argand	16·0	5·5	5·3	5·0	4·8	4·4	4·3
2	Sugg's table top, No. 4	14·0	6·6	5·9	4·5	4·4	4·3	3·5
3	,, ,, No. 5	15·0	6·3	5·3	4·7	4·6	4·4	4·0
4	,, ,, No. 6	17·0	6·7	6·2	5·1	4·9	5·0	4·2
5	,, ,, No. 7	24·0	9·0	7·9	6·7	6·5	6·4	5·8
6	Sugg's slit union, No. 4	12·0	7·1	5·4	4·4	4·3	4·2	3·4
7	,, ,, No. 5	15·0	8·5	5·8	5·2	5·0	4·8	4·5
8	,, ,, No. 6	20·0	7·9	6·7	6·1	5·9	5·8	5·1
9	,, ,, No. 7	18·0	7·2	6·3	5·4	5·2	5·0	4·5
10	Sugg's fishtail, No. 6	14·0	6·5	5·9	4·5	4·4	4·3	4·0
11	,, No. 7	10·0	5·3	4·3	3·4	3·3	3·1	3·0
12	Bray's fishtail, No. 4	8·6	6·9	5·3	3·5	3·4	—	2·3
13	,, No. 5	11·8	6·7	5·9	4·3	4·2	3·8	3·4
14	,, No. 6	12·4	8·0	5·4	4·3	4·2	4·2	3·6
15	,, No. 7	14·0	6·6	5·5	4·5	4·4	4·3	3·7
16	Bray's batswing, No. 6	17·0	7·8	6·8	5·4	5·2	5·2	4·5
17	Bray's union, with Codac economiser	15·0	5·7	5·1	4·5	4·4	—	4·2
18	Mint's batswing, No. 6	19·0	8·4	7·4	5·9	5·7	5·6	5·2
19	,, No. 7	17·0	7·3	6·2	5·4	5·2	5·1	4·6
20	Iron fishtail	3·0	4·8	4·3	2·1	2·0	2·0	1·5
21	Butcher's burner	26·0	10·0	9·2	8·1	7·9	7·5	7·0
22	Imitation Bronner, No. 4	10·0	4·4	3·8	3·5	3·4	3·1	2·8
23	Peebles, No. 4	9·0	5·4	4·5	3·5	3·4	3·3	2·8
24	,, No. 5	13·0	5·6	4·8	4·2	4·1	4·1	3·6
25	,, No. 6	15·0	6·0	5·7	4·7	4·6	4·6	4·4
26	Sugg's F Argand	20·0	7·1	6·4	6·0	5·8	5·6	5·3
27	Welsbach C burner and mantle	Max. intensity	4·0	4·0	3·4	3·3	3·5	2·9
29	Sugg's gov. burner table top (0·022)	18·0	—	6·4	5·7	5·5	5·2	4·7

TABLE XXIV.—*Table showing the Percentage Variation in the Quantity of Gas Consumed to yield Unit Light with each Burner when varying Qualities of Gas are used. Tests made with South Metropolitan Gas Company's Gas.* 100 *per cent.* = *that required with* 16·0 *Candle Gas.*

No.	Burners.	Illuminating power.	Consumption of gas per hour with					
			12·5	14·5	16·0	16·5	17·2	18·0
			Candle gas.					
1	Standard Argand	16·0	110	106	100	96	88	86
2	Sugg's table top, No. 4	14·0	147	131	100	93	93	78
3	„ „ No. 5	15·0	134	115	100	93	93	85
4	„ „ No. 6	17·0	131	122	100	96	98	82
5	„ „ No. 7	24·0	134	118	100	97	95	86
6	Sugg's slit union, No. 4	12·0	161	123	100	93	95	77
7	„ „ No. 5	15·0	163	112	100	96	92	86
8	„ „ No. 6	20·0	130	110	100	97	95	84
9	„ „ No. 7	18·0	136	119	100	98	94	85
10	Sugg's fishtail, No. 6	14·0	145	131	100	93	95	89
11	„ „ No. 7	10·0	156	127	100	97	91	88
12	Bray's fishtail, No. 4	8·6	198	152	100	97	—	80
13	„ „ No. 5	11·8	156	138	100	93	87	79
14	„ „ No. 6	12·4	186	126	100	98	98	84
15	„ „ No. 7	14·0	147	122	100	98	96	82
16	Bray's batswing, No. 6	17·0	145	126	100	96	96	83
17	Bray's union, with Codac economiser	15·0	127	113	100	98	—	93
18	Mint's batswing, No. 6...	19·0	143	126	100	97	95	88
19	„ „ No. 7...	17·0	135	115	100	96	94	85
20	Iron fishtail	3·0	229	205	100	95	95	71
21	Butcher's burner	26·0	123	117	100	98	93	86
22	Imitation Bronner, No. 4	10·0	126	109	100	97	89	80
23	Peebles, No. 4	9·0	154	129	100	97	94	80
24	„ No. 5	13·0	133	114	100	98	98	86
25	„ No. 6	15·0	128	121	100	93	98	94
26	Sugg's F Argand	20·0	119	107	100	97	93	88
27	Welsbach C burner and mantle...	Max. intensity	118	118	100	97	103	85
29	Sugg's gov. burner, table top (0·022)	18·0	—	114	100	96	91	82

DIAGRAM C.

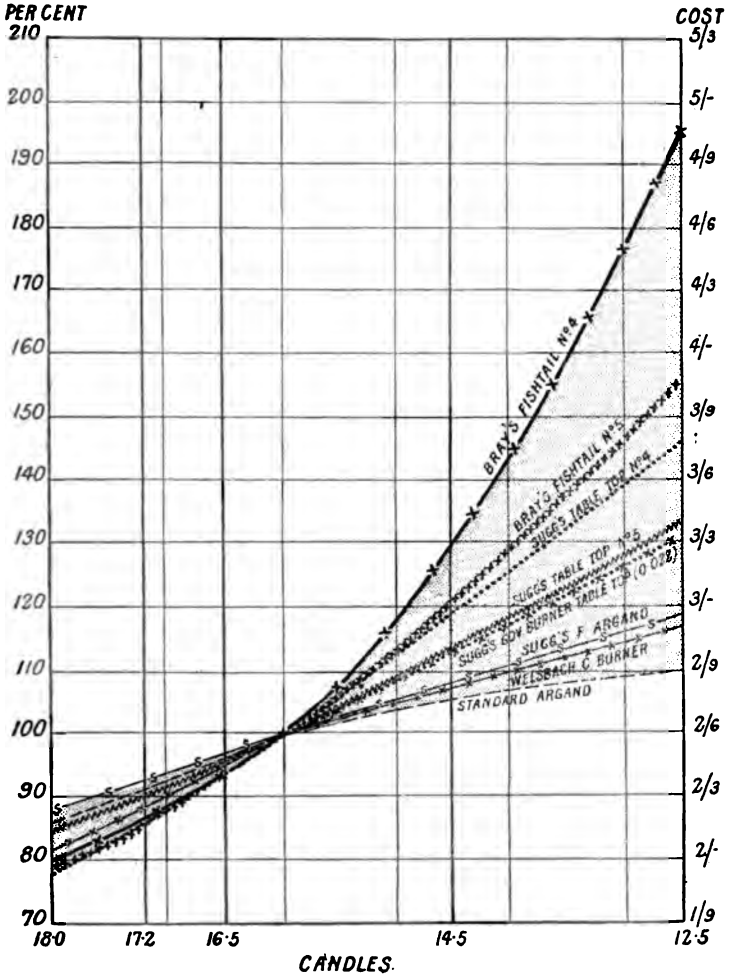

Diagram showing the percentage variation in the quantity of gas consumed to yield unit light with each burner when varying qualities of gas are used. Tests made with South Metropolitan Gas Company's gas. 100 per cent. = that required with 16·0-candle gas.

TABLE XXV.—*Table showing the Variation in the Quantity of Gas Consumed in each of a series of Burners to yield Unit Light with a Mixture of Low-power Coal and Water Gases in varying Ratios. Illuminating Power of both Coal and Water Gas = 14·5 Candles.*

No.	Burners.	Illuminating power.	Consumption of gas per hour with				
			Pure coal gas.	20	48	73	Pure water gas.
				Per cent. water gas.			
1	Standard Argand	16·0	5·2	5·3	5·6	5·4	5·4
2	Sugg's table top, No. 4	12·5	4·9	5·4	6·0	7·6	9·3
3	,, ,, No. 5	17·0	5·8	6·9	7·6	8·8	9·0
4	,, ,, No. 6	20·0	7·1	8·0	8·8	10·7	10·4
5	,, ,, No. 7	24·0	8·0	8·2	9·0	9·5	10·8
6	Sugg's slit union, No. 4	12·0	5·7	6·7	7·0	8·6	10·4
7	,, ,, No. 5	16·0	6·4	6·7	7·6	8·7	10·5
8	,, ,, No. 6	20·0	7·3	7·4	7·8	8·9	10·5
9	,, ,, No. 7	18·0	6·3	6·6	7·0	8·2	9·5
10	Sugg's fishtail, No. 6	14·0	6·0	6·6	8·1	9·2	9·8
11	,, ,, No. 7	10·0	5·2	5·6	6·2	7·5	8·7
12	Bray's fishtail, No. 4	8·0	5·6	6·8	7·6	9·6	14·5
13	,, ,, No. 5	12·0	6·9	8·0	8·7	9·4	16·3
14	,, ,, No. 6	13·0	7·1	7·6	8·0	10·4	13·8
15	,, ,, No. 7	17·0	7·9	8·6	9·5	11·5	15·7
16	Bray's batswing, No. 6	17·0	7·0	7·4	8·4	9·3	11·8
17	Bray's union, with Codac economiser	17·0	6·0	6·2	6·2	6·5	7·2
18	Mint's batswing, No. 6	20·0	7·5	8·0	8·6	10·6	12·0
19	,, ,, No. 7	21·0	7·7	8·0	8·6	9·7	13·0
21	Butcher's burner	26·0	10·4	10·4	10·8	11·8	12·2
22	Imitation Bronner, No. 4	10·0	4·3	4·4	4·2	4·5	5·1
23	Peebles, No. 4	7·7	4·4	4·1	4·5	5·2	6·7
24	,, No. 5	12·0	5·2	5·0	5·2	6·0	6·7
25	,, No. 6	13·5	5·1	5·6	5·8	5·9	6·7
26	Sugg's F Argand	20·0	6·5	6·7	6·8	6·8	6·8
27	Welsbach C burner and mantle	Max. intensity	3·9	3·6	3·9	4·0	3·9
29	Sugg's gov. burner, table top (0·022)	17·5	—	6·3	7·0	7·5	8·2

TABLE XXVI.—*Table showing the percentage Variation in the Quantity of Gas Consumed in each of a series of Burners to yield Unit Light with a Mixture of Low-power Coal and Water Gases in varying Ratios. Illuminating Powers of both Coal and Water Gas, 14·5 Candles.*

No.	Burners.	Illuminating power.	Consumption of gas per hour with				
			Pure coal gas.	Mixtures containing			Pure water gas.
				20	48	73	
				Per cent. water gas.			
1	Standard Argand	16·0	100	101	106	105	103
2	Sugg's table top, No. 4	12·5	100	109	121	153	188
3	,, ,, No. 5	17·0	100	119	131	152	155
4	,, ,, No. 6	20·0	100	112	124	150	146
5	,, ,, No. 7	24·0	100	103	112	119	135
6	Sugg's slit union, No. 4	12·0	100	117	123	150	183
7	,, ,, No. 5	16·0	100	105	119	136	164
8	,, ,, No. 6	20·0	100	101	107	123	144
9	,, ,, No. 7	18·0	100	105	111	130	151
10	Sugg's fishtail, No. 6	14·0	100	110	135	153	164
11	,, ,, No. 7	10·0	100	103	119	144	167
12	Bray's fishtail, No. 4	8·0	100	122	136	172	260
13	,, ,, No. 5	12·0	100	116	126	136	236
14	,, ,, No. 6	13·0	100	107	112	146	194
15	,, ,, No. 7	17·0	100	109	120	145	199
16	Bray's batswing, No. 6	17·0	100	106	120	133	169
17	Bray's union, with Codac economiser	17·0	100	103	103	108	120
18	Mint's batswing, No. 6	20·0	100	106	114	141	160
19	,, ,, No. 7	21·0	100	104	112	147	169
21	Butcher's burner	26·0	100	100	104	113	117
22	Imitation Bronner, No. 4	10·0	100	102	97	104	118
23	Peebles, No. 4	7·7	100	93	102	118	152
24	,, No. 5	12·0	100	96	100	115	129
25	,, No. 6	13·5	100	110	114	116	131
26	Sugg's F Argand	20·0	100	103	105	105	105
27	Welsbach C burner and mantle	Max. intensity	100	92	100	102	100
29	Sugg's gov. burner, table top (0·022)	17·5	100	156	130	193	210

low illuminating power, the ordinary supply was stripped by passing it through a coke scrubber, the coke being moistened with linseed oil. The richer gases were obtained by the addition of petroleum to the ordinary supply, and allowing the mixture of petroleum vapour and coal-gas to

TABLE XXVII.—*Table showing the Variation in the Quantity of Gas Consumed in each of a Series of Burners to yield Unit Light when varying Quantities of High-power Water Gas are mixed with High-power Coal Gas. Illuminating Power of both Coal and Water Gas* = 17·2.

No.	Burners.	Illuminating power.	Consumption of gas per hour with		
			Coal gas.	27 per cent. water gas.	75 per cent. water gas.
1	Standard Argand	16·0	4·7	4·7	4·7
2	Sugg's table top, No. 4	14·0	4·5	5·7	7·3
3	,, ,, No. 5	15·0	4·6	4·9	5·9
4	,, ,, No. 6	17·0	4·8	5·7	6·4
5	,, ,, No. 7	24·0	6·7	5·4	8·2
6	Sugg's slit union, No. 4	12·0	3·5	5·4	7·2
7	,, ,, No. 5	15·0	4·4	6·0	6·4
8	,, ,, No. 6	20·0	5·8	6·4	7·5
9	,, ,, No. 7	18·0	5·2	5·9	6·9
10	Sugg's fishtail, No. 6...	14·0	4·4	5·9	6·9
11	,, ,, No. 7...	10·0	3·4	4·8	6·5
12	Bray's fishtail, No. 4...	8·6	3·1	6·4	10·0
13	,, ,, No. 5...	12·8	4·0	5·0	11·1
14	,, ,, No. 6...	12·4	4·1	5·4	8·9
15	,, ,, No. 7...	14·0	4·1	5·2	9·1
16	Bray's batswing, No. 6	17·0	5·1	6·6	7·5
17	Bray's union, with Codac economiser	15·0	4·6	4·7	4·6
18	Mint's batswing, No. 6	19·0	5·7	6·8	8·6
19	,, ,, No. 7	17·0	5·1	5·7	6·3
21	Butcher's burner	26·0	7·9	8·8	9·2
22	Imitation Bronner, No. 4...	10·0	3·1	3·5	3·5
23	Peebles, No. 4	9·0	3·1	4·4	4·7
24	,, No. 5	13·0	4·1	4·9	5·1
25	,, No. 6	15·0	4·6	5·2	5·5
26	Sugg's F Argand	20·0	6·1	6·2	6·6
27	Welsbach C burner and mantle ...	Max. intensity	4·2	3·3	3·9

stand for some hours in a holder before making the tests. The results are set out in Tables XXI. and XXII. (see pp. 124 and 125) and Diagram "B" (see p. 126).

A third series was next made with gas supplied by the South Metropolitan Gas Company to the Southwark gas meter testing station of the London County Council, the

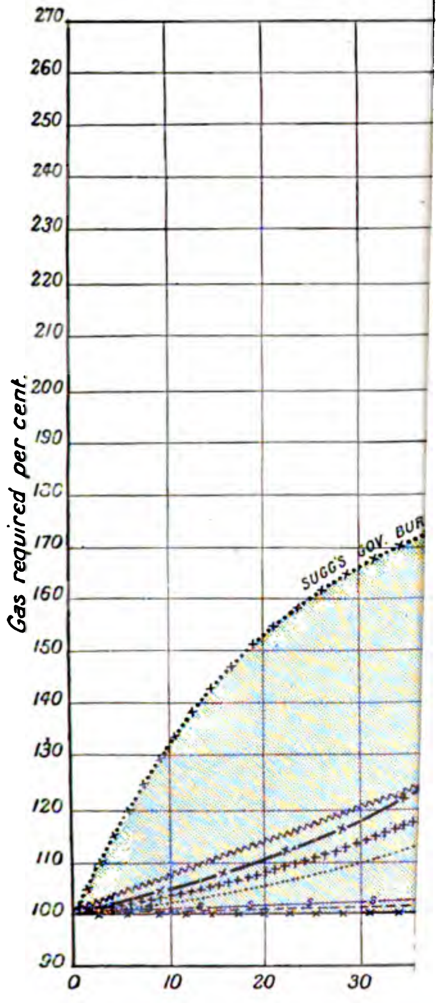

Diagram showing the percentage variation
yield unit light with a mixture of low-p
both coal and water-gas = 14·5 candles,

To face page 132.]

rich gas being obtained in the same way. The results are set out in Tables XXIII. and XXIV. (see pp. 127 and 128) and Diagram " C " (see p. 129).

The results confirmed those first arrived at.

For the purpose of ascertaining the effect of the use of water-gas, the author conducted a similar series of tests, three in number, viz., first with a mixture of lower power coal-gas and water-gas in varying ratios; second with mixtures of high-power coal-gas and water-gas; and the third with high-power water-gas and low-power coal-gas.

TABLE XXVIII.—*Table showing the Percentage Variation in the Quantity of Gas Consumed in each of a Series of Burners to yield Unit Light when varying Quantities of High-power Water Gas are mixed with High-power Coal Gas. Illuminating Power of both Coal and Water Gas* = 17·2.

No.	Burners.	Illuminating power.	Consumption of gas per hour with		
			Coal gas.	27 per cent. water gas.	75 per cent. water gas.
1	Standard Argand	16·0	100	100	100
2	Sugg's table top, No. 4	14·0	100	127	161
3	,, ,, No. 5	15·0	100	106	178
4	,, ,, No. 6	17·0	100	119	133
5	,, ,, No. 7	24·0	100	110	123
6	Sugg's slit union, No. 4	12·0	100	155	206
7	,, ,, No. 5	15·0	100	136	145
8	,, ,, No. 6	20·0	100	110	129
9	,, ,, No. 7	18·0	100	113	133
10	Sugg's fishtail, No. 6	14·0	100	134	157
11	,, ,, No. 7	10·0	100	141	191
12	Bray's fishtail, No. 4	8·6	100	206	323
13	,, ,, No. 5	12·8	100	125	277
14	,, ,, No. 6	12·4	100	132	217
15	,, ,, No. 7	14·0	100	125	219
16	Bray's batswing, No. 6	17·0	100	129	147
17	Bray's union, with Codac economiser	15·0	100	102	100
18	Mint's batswing, No. 6	19·0	100	119	151
19	,, ,, No. 7	17·0	100	112	123
21	Butcher's burner	26·0	100	111	116
22	Imitation Bronner, No. 4	10·0	100	111	111
23	Peebles, No. 4	9·0	100	142	152
24	,, No. 5	13·0	100	119	124
25	,, No. 6	15·0	100	113	120
26	Sugg's F Argand	20·0	100	101	107
27	Welsbach C burner and mantle	Max. intensity	100	79	93

The results are set out in Diagrams " D " (facing p. 132) and "E" (see p. 135), and Tables XXV. to XXX. (see pp. 130 to 136).

From Diagram D (facing p. 132) and Tables XXV. and XXVI. (see pp. 130 and 131), it will be seen that with increased percentages of water gas the quantity of gas required to give unit light with a Bray's No. 4 burner rose to as much as 160 per cent., whilst with the standard

TABLE XXIX.—*Table showing the Variation in the Quantity of Gas Consumed in each of a Series of Burners to yield Unit Light when Varying Quantities of High-power Water Gas are Mixed with Low-power Coal Gas, the High-power Water Gas being used as an Enriching Agent.*

No.	Burners.	Illuminating power.	Consumption of gas per hour with		
			16·0	17·2	18·0
			Candle-power gas containing		
			Pure coal gas	27 per cent. water gas.	50 per cent. water gas.
1	Standard Argand	16·0	5·0	4·7	4·6
2	Sugg's table top, No. 4	14·0	5·4	5·7	5·0
3	,, ,, No. 5	15·0	5·4	4·9	4·9
4	,, ,, No. 6	17·0	5·7	5·7	5·7
5	,, ,, No. 7	24·0	7·8	5·4	7·4
6	Sugg's slit union, No. 4	12·0	4·6	5·4	5·3
7	,, ,, No. 5	15·0	5·4	6·0	5·4
8	,, ,, No. 6	20·0	6·4	6·4	6·4
9	,, ,, No. 7	18·0	6·1	5·9	5·5
10	Sugg's fishtail, No. 6	14·0	5·2	5·9	5·3
11	,, ,, No. 7	10·0	4·2	4·8	4·3
12	Bray's fishtail, No. 4	8·6	4·4	6·4	5·4
13	,, ,, No. 5	12·8	5·1	5·0	4·8
14	,, ,, No. 6	12·4	5·1	5·4	5·4
15	,, ,, No. 7	14·0	5·2	5·2	5·2
16	Bray's batswing, No. 6	17·0	5·8	6·6	6·2
17	Bray's union, with odac economise	15·0	5·0	4·7	4·6
18	Mint's batswing, No. 6	19·0	6·7	6·8	6·4
19	,, ,, No. 7	17·0	5·6	5·7	5·7
21	Butcher's burner	26·0	8·5	8·8	8·0
22	Imitation Bronner, No. 4	10·0	3·5	3·5	3·4
23	Peebles, No. 4	9·0	3·6	4·4	4·1
24	,, No. 5	13·0	4·6	4·9	4·2
25	,, No. 6	15·0	5·1	5·2	4·8
26	Sugg's F Argand	20·0	6·4	6·2	6·2
27	Welsbach C burner and mantle ...	Max. intensity.	3·5	5·7	4·0

Diagram E.

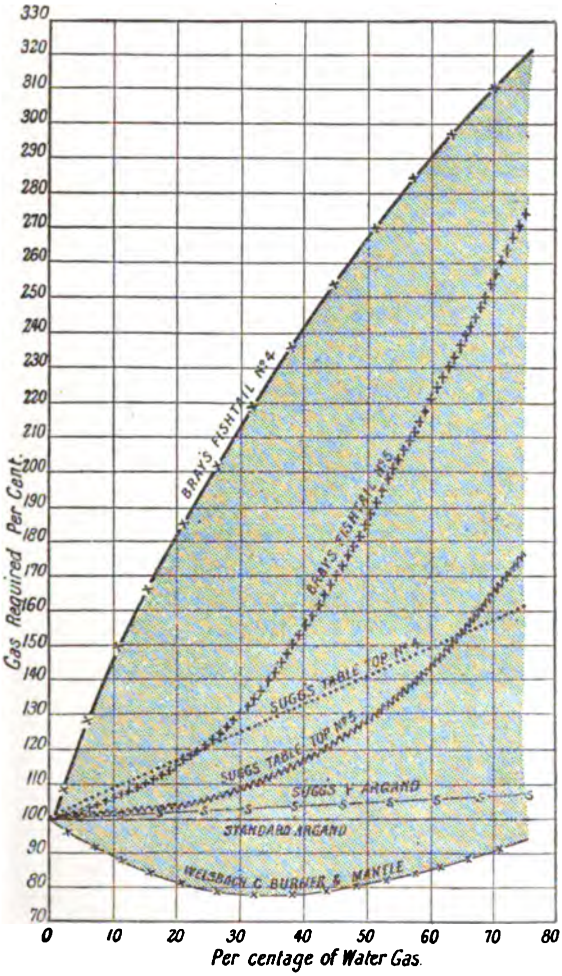

Diagram showing the percentage variation in the quantity of gas consumed in each of a series of burners to yield unit light when varying quantities of high-power water-gas are mixed with high-power coal-gas. Illuminating power of both water and coal-gas = 17·2 candles.

Argand burner the increase was only 6 per cent., and with the Welsbach mantle it was nil.

In the tests with high-power coal and water gas—Diagram E (see p. 135) and Tables XXVII. and XXVIII.

TABLE XXX.—*Table showing the Percentage Variation in the Quantity of Gas Consumed in each of a Series of Burners to yield Unit Light when Varying Quantities of High-power (20·0 candle) Water Gas are Mixed with Low-power Coal Gas, the High-power Water Gas being used as an Enriching Agent.*

No.	Burners.	Illuminating power.	Consumption of gas per hour with		
			16·0	17·2	18·0
			Candle-power gas containing		
			Pure coal gas	27 per cent. water gas.	50 per cent. water gas.
1	Standard Argand	16·0	100	94	92
2	Sugg's table top, No. 4	14·0	100	105	93
3	,, ,, No. 5	15·0	100	91	91
4	,, ,, No. 6	17·0	100	100	100
5	,, ,, No. 7	24·0	100	95	95
6	Sugg's slit union, No. 4	12·0	100	117	115
7	,, ,, No. 5	15·0	100	111	100
8	,, ,, No. 6	20·0	100	100	100
9	,, ,, No. 7	18·0	100	97	90
10	Sugg's fishtail, No. 6	14·0	100	114	102
11	,, ,, No. 7	10·0	100	113	101
12	Bray's fishtail, No. 4	8·6	100	145	123
13	,, ,, No. 5	12·8	100	98	94
14	,, ,, No. 6	12·4	100	106	106
15	,, ,, No. 7	14·0	100	100	100
16	Bray's batswing, No. 6	17·0	100	114	107
17	Bray's union, with Codac economiser	15·0	100	94	92
18	Mint's batswing, No. 6	19·0	100	102	95
19	,, ,, No. 7	17·0	100	102	102
21	Butcher's burner	26·0	100	104	94
22	Imitation Bronner, No. 4	10·0	100	100	97
23	Peebles, No. 4	9·0	100	122	114
24	,, No. 5	13·0	100	107	91
25	,, No. 6	15·0	100	102	94
26	Sugg's F Argand	20·0	100	97	97
27	Welsbach C burner and mantle	Max. intensity.	100	94	114

(see pp. 132 and 133)—with Bray's No. 4 fishtail burner, the increase in consumption was 220 per cent. with 75 per cent. water gas, but with the standard Argand there was no increase, whilst with the Welsbach mantle there was an actual decrease in the consumption of 7 per cent.

Tables XXIX. and XXX. show the effect of water gas when used as an enriching agent.

Briefly stated, the results of the water gas series are that dilution of coal gas with equal power water gas has the same effect in many burners as that produced by a reduction of the illuminating power of the gas, *i.e.*, a larger quantity of gas has to be consumed in order to obtain the same illumination, whilst the use of excessive quantities of high-power water gas as an enriching agent is without the commensurate advantages that might have been anticipated, viz., such as are obtained from the use of benzol, cannel, &c.

The Standard Burner for Gas Testing and Method of Consuming the Gas therein.—From the foregoing discussion of the behaviour of different gases in different burners, it will be seen that before any definite expression of value can be ascribed to a gas, the conditions of its consumption must be accurately determined. For this purpose what is known as the "London Argand No. 1" is now generally adopted for ordinary gas, and for richer gases, such as gas made from cannel coal, a flat-flame burner is used. The London Argand is described as follows in the Gas Referees' Notification:—

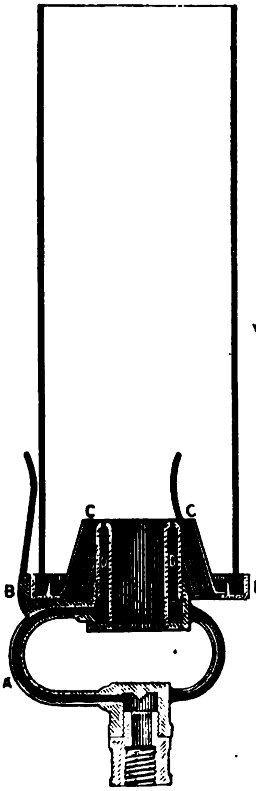

Fig. 22.

The burner which has been adopted as the standard burner for testing gas was designed by Mr. Sugg, and was called by him "Sugg's London Argand, No. 1."

A full-sized section is shown in Fig. 22, in which A represents a supply pipe, B the gallery, C the cone, D the steatite chamber, E the chimney.

The following are the dimensions of those parts of the burner upon which its action depends:—

	In.
Diameter of supply pipes	**0·08**
External diameter of annular steatite chamber	**0·84**
Internal diameter of do.	**0·48**
Number of holes	**24**
Diameter of each hole	**0·045**
Internal diameter of cone:	
At the bottom	**1·5**
At the top	**1·08**
Height of upper surface of cone and of steatite chamber above floor of gallery	**0·75**

For testing the gas of the Gas Light and Coke and of the Commercial Gas Companies (which is required to have an illuminating power of 16 candles) the chimney shall be 6in. long and 1⅞in. in internal diameter.

Sec. 6 of the South Metropolitan Gas Act, 1900, reads as follows:—

"The burner for testing gas supplied by the company shall be Sugg's London Argand, as prescribed by Sec. 38 of the South Metropolitan Gas Light and Coke Company's Act, 1876, and in making such testings shall be so used that the gas shall be burnt at such a rate as shall give a light equal to 16 candles:

"Provided that when under the provisions of this Act the prescribed illuminating power shall be 14 candles, the said burner shall be used with the chimney prescribed by the Gas Referees for an illuminating power of 14 candles."

The Gas Referees are advised that the words "prescribed by the Gas Referees" in the section of the Act above quoted refer to a prescription in the Notification of the Gas

Referees for the summer half-year 1876, and for several previous years, which is as follows :—

" For testing the gas of the Imperial Gas Company and of the South Metropolitan Gas Company (both of which are required to have an illuminating power of 14 candles) the burner shall be the same [*i.e.*, a 'Sugg's London Argand, No. 1 '], but shall be used with a chimney, 6in. long by 1¾in. diameter.

" If at any time the gas flame mounts above the top of the chimney, a 6in. by 2in. chimney shall be substituted for the 14-candle gas."

The system of testing formerly prescribed and adopted was to consume the gas in the standard burner at the rate of 5 cubic feet per hour, whatever the quality of the gas may be. Thus, if it is an "ordinary" gas of extra good quality, this volume of gas may give a light equal to 17 or 18 candles, and the chimney of the burner will be full of flame, thus requiring and using up all the oxygen which can gain admittance to the burner. On the other hand, if the quality of the gas be very poor, say 14 or 13 candles, or even less, then the flame will be deficient in volume, and will be supplied with more oxygen than is required, and hence will be over-burnt, whilst if the quality be even less than this the character of the flame will be so poor, by reason of its over-oxidation, as to be comparable to that of a Bunsen burner.

These considerations have naturally led to many speculations, and various suggestions have been made. These were carefully reviewed by Dr. W. Pole in a series of articles which he contributed to the *Journal of Gas Lighting* in October, 1870, and therein he laid down what is known as "Pole's law," by means of which it is possible to accurately gauge the quality of a gas in the standard burner, whatever that quality may be, instead of having to employ various burners for various gases, and thus destroying any reliable comparisons between them, as the conditions of consumption necessarily varied with each new burner. By the use of one standard burner these variations would be done away with, and reliable comparisons made. As expressed by himself, Dr. Pole's law is as follows:—

"*That during the normal state of action of a gas burner, the light given varies directly as the consumption, minus a constant quantity.*"

"In algebraical language, let q = quantity of gas consumed per hour in a given burner, and L = light produced thereby.

"Then, while according to the original erroneous assumption,

$$L \text{ varies as } q,$$

and, according to Farmer's equally erroneous theorem,

$$L \text{ varies as } q^2,$$

the true law appears to be

$$L \text{ varies as } A\,(q - c)$$

where c is constant for the same burner."

"The principle involved in this law appears to be somewhat as follows:—When the quantity of gas supplied to the burner is very small compared to its normal capacity, it is burnt at a disadvantage, having an excess of air; it is, in fact, in the position of a Bunsen burner. Hence, as has been often explained, the deposition of the light-giving particles is impeded, the flame burns blue, and the light developed is smaller than is fairly due to the gas employed. But as more and more gas is admitted, this defect tends gradually to remedy itself, until a point arrives where a normal and proper condition is reached; and *beyond that point every increment of gas gives a corresponding and uniform increment of light.* The quantity of gas necessary to develop this condition in the first instance is represented in our equation by the constant c; and, for want of a better name, I may call it the developant for that burner. This quantity, though constant for the same burner, varies materially for different kinds of burners, and also under other changes of condition."

This law was investigated by Messrs. Heisch and Hartley, who discussed their results in a paper read by them before the Gas Institute in 1884, in which they gave the following :—

"*Rules for the use of the factors 'A' and 'C' when it is desired to express the power of any gas at 5 cubic feet rate per hour*:—

"(1) Correct the actual rate of consumption for barometric pressure, and for temperature of the gas, by the aid of factors in the published tables.

"(2) Multiply the difference between the actual rate of consumption (corrected) and 5 cubic feet by the factor 'A' due to the quality of the gas. (*a*) If the rate of gas be *below* 5 cubic feet, *add* the product to the observed amount of light. (*b*) If the rate be *above* 5 cubic feet, *subtract* the product from the observed amount of light."

The following abstract is taken from Messrs. Heisch and Hartley's valuable paper:—

"The following Table XXXI. of actual tests with gas of very nearly 15 candle power exemplifies our method; while the last column shows the grave errors which result from the present system of correcting illuminating power to the standard rate. Only ordinary care was taken in making the tests, as may be judged when the fact is stated that the whole series of observations were completed in half an hour.

From these results it will be seen that the new method gives a far more uniform, indeed practically equal, value for the gas, with consumptions varying from 4·25 cubic feet per hour to 5·37 cubic feet.

The importance of this alteration will be seen in connection with the table photometer of Mr. Harcourt now being introduced at the Metropolitan Gas Testing Stations, and which will have the effect of considerably modifying the tests of very poor gas in favour of the companies, against the old system of always burning exactly 5 cubic feet per hour under all circumstances.

TABLE XXXI.

Table showing the New Method of Correcting for Rate.

Nearly 15 candle gas; multiplier, 6·3.

Rate of gas by meter.	Tabular No.	Corrected rate for gas.	Excess or deficit in rate.	Product of excess or deficit and multiplier.	Observed illum. power.	Illum. power, corrected to 5ft. rate.	Calculated to 5 cubic feet rate by old rule.
4·250	994	4·225	·775	4·890	9·80	14·690	11·600
4·400	994	4·374	·626	3·946	10·90	14·846	12·460
4·500	994	4·473	·527	3·235	11·50	14·735	12·850
4·600	994	4·572	·428	2·696	12·10	14·796	13·232
4·700	994	4·672	·328	2·066	12·82	14·886(?)	13·720
4·800	994	4·772	·228	1·376	13·40	14·776	14·040
4·850	994	4·821	·179	1·128	13·80	14·928	14·313
5·000	994	4·970	·030	0·189	14·72	14·909	14·808
5·072	994	5·088	·088	0·239	15·00	14·761	14·876
5·370	994	5·338	·338	2·139	16·70	14·561	15·642
Per cent. extreme differences						2·500	34·800

CHAPTER IX.

METHODS OF ENRICHMENT.

It was shown by the experiments of Mr. Lewis T. Wright, quoted in the previous section, that the quality of the gas may vary considerably according to the manner in which the distillation is conducted. It will be understood that we are not here concerned with all the variations which may take place, either intentionally or unintentionally, but have merely to consider the subject in its general bearings with a view to an intelligent understanding on the part of the student of so much of the question as will enable him to form an opinion of the merits or demerits of various systems of artificial illumination. One of the first things that have to be considered with regard to the best means of utilising coal gas is the quality, which has to be dealt with in order that the most suitable burner or burners may be selected for the work.

It will be seen that if the comparison of cost is to be made in relation to a gas of 20 candle-power, the argument will be very different from that founded upon a quality of 15 candles, whilst in each case the price of the gas has also to be taken into account. In many cases it is assumed that the quality of the gas supplied to the consumer will be that specified in the companies' Act of Incorporation, but this is not invariably the case, and if reliable comparisons of cost are to be made, the actual illuminating power of the gas at the place in question must be ascertained and considered.

It being clear that the quality of the gas is under the control of the maker, whose province it is to produce it of a given illuminative value at the lowest market price, we have next to consider whether the different modes of enriching a gas when necessary to raise it to the standard quality have any effect on the methods of combustion generally employed.

The methods employed by the gas maker for increasing the quality of the gas are as follows:—

(1) Admixture of a richer gas, such as that obtained from cannel coal.

(2) The diffusion into the gas of the vapour of light petroleum oils, such as benzoline, carburine, gasoline, &c.

(3) Addition of rich gases obtained by the destructive distillation of tar, &c., which may be added to the coal at the time of its admission to the retort.

(4) Mixing with the gas other gas obtained by the decomposition of crude oils.

(5) The addition of "water gas" enriched with light petroleum oils made more or less permanent by the action of heat.

The first of these may be termed the "old-fashioned" method, having been in general use for many years, but in consequence of the high price of cannel coal, various substitutes have been employed, with the result that the behaviour of the enriched gas flame in a burner is very different from that of the gas produced simply from coal alone. For instance, with coal gas of 16-candle quality a flame produced by the consumption of five cubic feet per hour in a standard Argand burner would be as nearly as possible 3in. in height. By the introduction of some of the rich gases obtained by superheating petroleum spirit, &c., the height of the flame required to produce the same intensity of light would be about 2½in. in height, or less; thereby giving a more concentrated illumination, although of the same total luminous energy. This effect is greatly enhanced in regard, say, to 20-candle gas from coal, which cannot be properly burnt in the standard London Argand burner with a 6in. chimney, as the flame tails out of the top of the chimney in a long trail of smoke. Yet when a

20-candle oil gas is burnt in the same burner the height of the flame may not be more than from 2¼in. to 2½in. We have only to carry the comparison one step further to make the point perfectly clear. Let the reader consider the extremely small flame necessary to produce a light of almost any candle-power by the combustion of acetylene, and he will readily understand how variations in the methods of enriching ordinary coal gas will influence its behaviour on combustion in any given burner.

There is a method of enriching gas, not included in the above, which has come into use very largely during the past fifteen years, viz., the albo-carbon system. In this the gas is heated on its way to the burner, and passes over melted naphthalene, a certain quantity of which it takes up and carries forward to the point of ignition, with the result that a very considerable increase in the illumination is obtained. This will, however, be more fully considered later on.

CHAPTER X.

GAS METERS.

In pursuance of the scheme of the present work, it will now be necessary to explain the method adopted for the measurement of gas intended for use as an artificial illuminant. The average householder has a rooted conviction that by some mysterious means the gas company always manages to get the whip hand in regard to the measurement of the quantity of gas consumed. All that he knows is that there is a thing called a "meter" somewhere in his house, generally in the coal-cellar or other inconvenient and all but inaccessible place, and that from time to time the "gas man" wants to look at it, and then sends in his bill, which most householders firmly believe is a great deal too high; and that when the company are so inclined, they have the power of "forcing the gas through the meter" to their heart's content. Although there may in some cases be good ground for complaint as to the amount of the bill, and honest John Bull feels that, whatever the cause may be, he has not had the full value for his money, yet the cause of the trouble has seldom anything to do with the meter, as will be seen from Chapter VIII., in which we considered the effect of the quality of the gas supplied in relation to its use in various burners, and the light obtained thereby. A good gas meter—and there are really very few bad ones—is a beautiful scientific instrument, constructed to most exact measurements, and tested under the most rigid conditions before it is allowed to be used. In fact, any person using a meter which does not bear the official stamp issued by the

Standards Department of the Board of Trade, and that of the official Gas Meter Inspector appointed by the ratepayers, *i.e.*, the County Council or the Justices of the Peace, is liable to a fine of £5.

In the early stages of gas manufacture by private individuals and companies, and after this industry had become a commercial success, it naturally followed that manufacturers should turn their attention to some mode by which they could check the amount of gas supplied to the consumers. Their first step in this direction was to arrange with the consumer that he should burn gas for so many hours from a given burner, naming the time the gas should be lit and extinguished; but this led to continual disputes, owing, in most cases, to dishonesty on the part of the consumer, or to groundless suspicions that the supplier was being taken advantage of. This method was also expensive, owing to the necessity of the gas manufacturer having to employ a large number of detective Inspectors to see that the lights were lit and extinguished at the proper times. The demand was therefore created for an instrument which would accurately measure the amount of gas delivered.

Probably a gas meter is the most ill-used piece of mechanism in existence. It has to register an elastic gas driven through it at different pressures. It is fixed as a rule in draughty, damp, and unsuitable places. Its works are as intricate as those of a watch. Its various sliding and other movements are more numerous than those of an engine. Further than this, the majority of its parts have to work surrounded by gas, which necessarily must leave deposits of gas liquor of a sticky nature. All this mechanism has to be enclosed in a hermetically sealed case, without any means of lubricating or cleaning the parts; but, notwithstanding its being thus treated, it will remain at work for many years, and when taken down and placed upon the test table of the Government Inspector appointed under the "Sales of Gas Act" it is found in most instances to register correctly, or only show a small percentage of error.

Gas meters are divided into two classes—dry and wet meters. Both have advantages and disadvantages; but the dry meter has for many years past been in the ascendency.

The dry meter is, roughly speaking, an instrument composed of valves, which open and close to admit or let out gas to or from chambers which have a moving part expanding or contracting, according to whichever side of the disc the pressure of gas is exerted. These discs are connected to the valves by means of rods and levers to control the flow of gas. They are fixed measurers of gas, and the registration of the meters cannot be tampered with without damage to the outside case.

The wet meter is an instrument composed of a series of chambers, or holders, which, after receiving the gas, dip into water or some other fluid, and are driven out again by the pressure of gas. By this pressure on the succeeding chamber the motive power is gained. The capacity of these chambers is dependent for their correct registration on the quantity of water in the meter, which necessarily varies through evaporation. This causes great inconvenience by condensation in the fittings, and necessitates occasional attendance to replace the water, and special care to prevent it from freezing.

Early dry meters. — There is little doubt that the original idea of a dry meter was taken from a pair of bellows, it being acted upon by the pressure of gas to make it expand and contract, the direction of the gas to the chambers being regulated by valves. Various materials were tried for the flexible part of the bellows, hereafter described as diaphragms. The following are some of the materials:—Silk, canvas, thin metal, india-rubber in the form of macintosh, parchment, gold-beaters' skin, &c., the pores of which were filled up with oil, wax, gums, and many other substances, but none have succeeded so well as the employment of leather, which, if properly selected and dressed, remains pliable and soft for any length of time, because the gas is always depositing small particles of oil on to the leather during the time the meter is working, and thus lubricating it. The diaphragms have been tried on the top, sides, and bottom; also horizontally and perpendicularly, but none have been so successful as those placed perpendicularly in the lower portion of the meter.

With regard to the valves which control and direct the flow of gas to the diaphragm, taps, spring valves, throttle valves, click valves, and rotary valves; whilst iron, porcelain, brass, china, gun-metal, leather, and other substances have been tried, but experience has shown that an ordinary D-slide valve, with a setting of three port-holes made of anti-corrosive white metal, is the best.

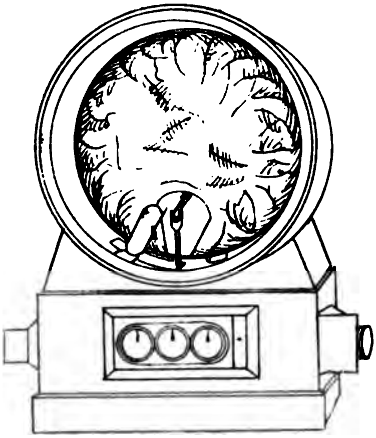

Fig. 23.

Fig. 23 shows one of the earliest forms of dry meters. It is a single diaphragm contained in a circular case placed above the valve chamber, which is at the bottom of the meter, behind the index. This valve alternately allows the gas to flow into the back and front of the diaphragm, causing the diaphragm to fall forward, owing to the pressure of gas playing on the back. This motion shifts the valve and brings the pressure of gas on to the front. The diaphragm then goes back to its former position, each pulsation discharging a given quantity of gas, which passes away into the consumer's fittings.

The defect in this meter, however, was that owing to the clumsy form of the diaphragm and the action of a "tumbler" controlling the valves, the lights were very unsteady—a defect which was very much added to by the bagginess of the leather of the diaphragm. The quantities of gas discharged by it were uncertain, and therefore the registration was defective. Being hinged at the bottom, it required an extra pressure of gas to raise the diaphragm over the centre of gravity, and directly it arrived at this point, on its downward path, it dropped with a jerk, with disastrous results to its effectual working. This form was very soon condemned.

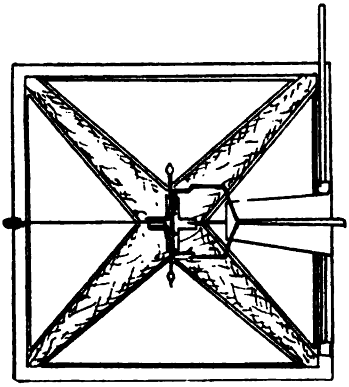

Fig. 24.

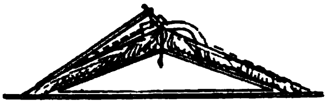

Fig. 25.

A great advancement was made with another meter similar to this one, by the following additions and alterations:—Two diaphragms were introduced instead of one, which were better supported with a rod and hinged tee piece. Their position, as well as that of the valves, was reversed, the diaphragm being placed at the bottom of the meter, whilst the valves were placed at the top. Although this somewhat reduced the two defects of the previous meter, it was still imperfect.

The next improvement was the introduction of a diaphragm of the shape shown in Figs. 24 and 25. This was the first dry meter from which a steady light was obtainable. The construction of the diaphragm was as follows:—Into a square metal frame was fixed a sheet of leather, which had previously been blocked into a conical shape. Attached to this leather were four triangular shields, so placed that they formed a hinge between the square frame and the base of the triangular pieces A flexible partition was also formed between the sides of these triangles. These shields were supported at the vertex by a four-armed tee piece, attached to a flag and rod. The construction of the rod allowed it to move steadily backwards and forwards when acted upon by the gas under the control of the valves similar to the former meters. The meter was sometimes fitted with two diaphragms, but more often with three. It was also fitted with D sliding valves, made of white-metal and gun-metal, but the majority were made with a circular valve and grating, the valve being made of leather, the grating of white metal. This meter worked remarkably well for many years, but, owing to the leather having to pass the point of attachment in the square metal frame at each movement and forming a hinge, the bottom part cracked and split, which allowed the gas to pass through the meter unregistered.

After several improvements, a pattern was arrived at which is now adopted by nearly all the leading makers, not only at home, but abroad and in the Colonies. Considerably more than two thirds of all the meters made—whether wet or dry—are constructed on these lines.

What is known as a "five-light meter," which is illustrated in the accompanying drawing, is taken as an example, and in order that its construction may be fully understood, and the various actions followed in their proper

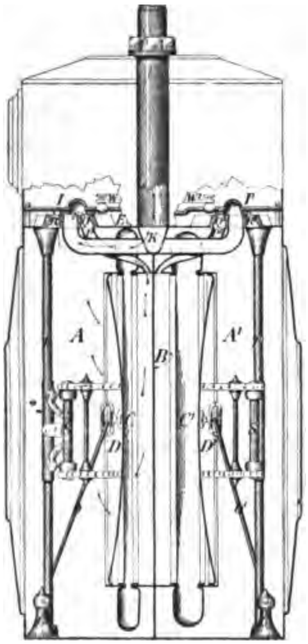

Fig. 26.

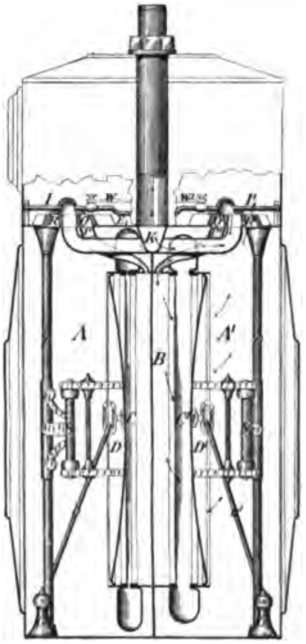

Fig. 27.

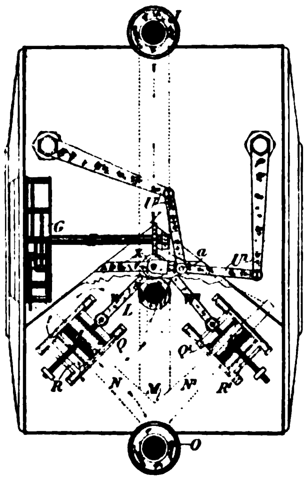

Fig. 28

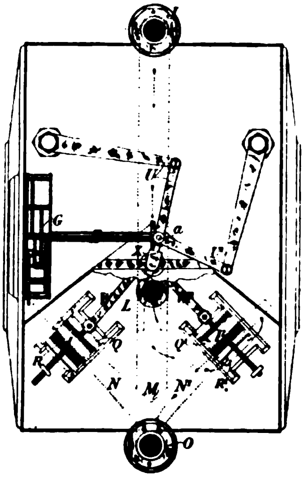

Fig. 29.

sequence, several views are depicted, in which Figs. 26, 27, 30, and 31 are vertical cross-sections upon a line approximately mid-way through the bellows and valves. Figs. 28, 29, 32 and 33 are plans with the top cover removed and a portion of the valve box broken away to more clearly show the relative positions and action of the valves.

Fig. 34 is a front elevation with the front removed and partly in section, while Fig. 35 is an under-plan showing more particularly the construction of the valve plate. Fig. 36 represents the front view of the completed meter.

Throughout the following description, and in the several views, like letters are used to denote like parts. Furthermore, the respective views represent the meter mechanism in its various phases throughout a complete cycle of operations.

The body of the meter is divided vertically into two chambers A A^1 by the plate B, to which plate—on either side—are attached the flexible bellows C C^1 and diaphragms D D^1.

The body of the meter is also divided horizontally by the plate E, thereby forming a chamber above for the reception of the registering mechanism G—Figs. 28, 29, 32, and 33 Upon the top of the plate E, and within the chamber F (see Fig. 34), is formed a box H, which contains the valves I I^1, covering port-holes that communicate respectively with the *interior* and *exterior* of the bellows on either side of the vertical division B, as fully explained later. It will be noticed that the inlet J (on the left-hand side of Fig. 34) communicates with a passage K on the underside of the plate E, which latter has an orifice L leading into the valve box H. This passage K has a dead end at M, formed by the intersection of the two channel plates N N^1, as can be very clearly seen by Fig. 35 (page 157). These channels N N communicate respectively with the exhaust ports of the valves and the outlet pipe O. The foregoing valves I I^1 are known in steam practice as D valves, and they work upon a grid having three openings or ports, the middle port

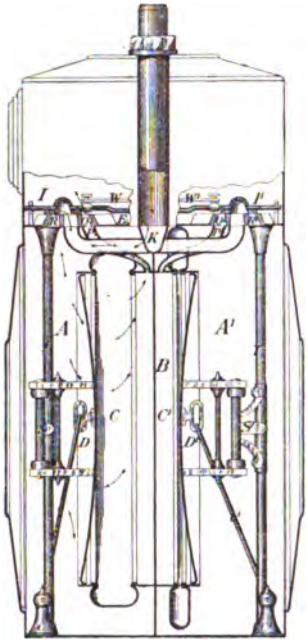

Fig. 30.

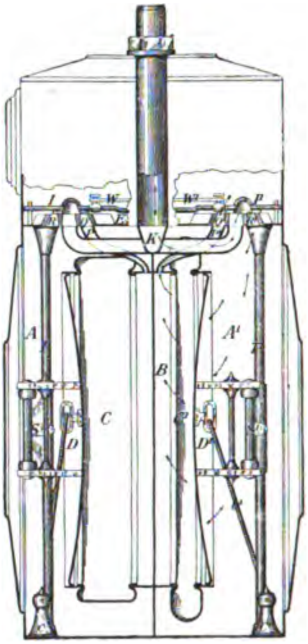

Fig. 81.

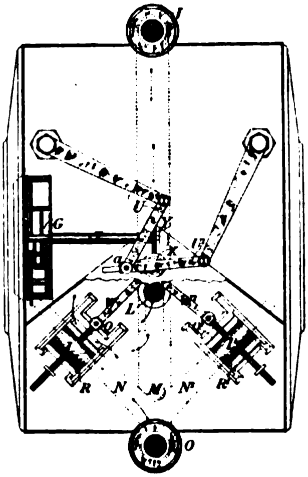

Fig. 32.

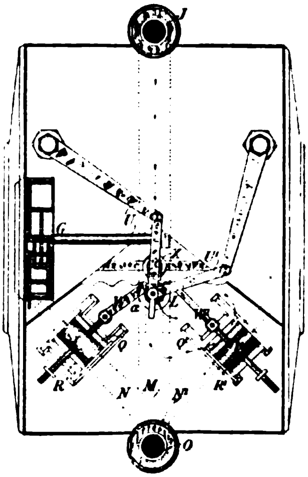

Fig. 33

being known as the exhaust port, which communicates with the channels N N^1, as previously pointed out. One of the other two ports Q Q^1 of each valve opens into the *interior* of the bellows C C^1 by a communicating pipe P P^1, soldered on either side of the vertical division B. The other port

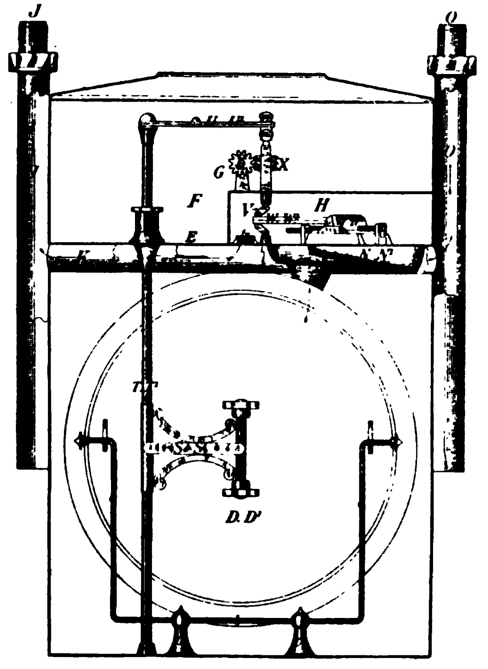

Fig. 34.

R R^1 of the valves opens into the body chamber A A^1, but *outside* the bellows.

The diaphragms D D^1 of each bellows are attached by a hinge S S^1 to flagwires T T^1 that pass into the chamber F through stuffing-boxes and glands (see Fig. 34) that effectually prevent the escape of gas into the said chamber, but at the same time allow the flagwires T T^1 to turn freely, and transfer motion by means of the connecting links U U^1 (see Figs. 28, 29, 32, 33, and 34) to the spindle V, that passes through a stuffing-box to the interior of the valve box H. The lower end of the spindle V is formed as a crank, and is connected to the D valves I I, by links W W^1.

These valves and the ports they cover are arranged at an angle of 45 deg. to a line drawn through the centre of the meter, which, therefore, gives an advance movement of one valve over the other of about 90 deg., with the object of ensuring that the flow of gas through the meter is uninterrupted.

Upon the top of the spindle V is fitted a worm X, which, by a wheel Y and spindle Z, communicates motion to the train of gearing G.

Presuming in the first place that the air has been driven out of the meter, and that gas is passing into the inlet J, from which to the outlet O its passage will be traced consecutively, the method of operation is as follows:—

Referring more particularly to Fig. 34, the gas passing down the inlet pipe J enters the channel K, passes through the orifice L into the chamber H; the valves at this juncture being in the position shown in Figs. 26, 28—that is to say, the port R of the valve is fully open to allow the gas to pass through in the direction indicated by the arrows to fill the chamber A, and, by its pressure upon the diaphragm D, cause it to close in and expel the gas through the passage P, port Q, and under the valve, through the exhaust into the channel N to the outlet O (Fig. 34), thence into the consumer's pipes.

As the diaphragm D moves under the pressure of the gas, it turns, by means of the hinge S, the flagwire T, and rotates the crank spindle a quarter turn, by this means bringing the valves into the position shown in Figs. 27 and 29, in which the corresponding valve port R^1 is now fully open to admit gas to the chamber A^1, press on the diaphragm D^1, expel the gas in C^1, through the pipe P^1 port Q^1 under valve, through exhaust, into the channel N^1 to the outlet O, as before described with reference to the chamber A.

The diaphragm D in its movement inwards has communicated motion to the crank spindle V (Fig. 34) in the same manner as the previous one, and has gradually moved the valves to the position shown in Figs. 30, 32, in which it will be noticed that the port Q is fully open for the gas to enter by the channel P and fill the bellows to the utmost extent of its movement, and expel the gas previously fed into the chamber A back through the port R, under the valve through the exhaust port, to the channel N, and thence by pipe O to outlet, by which time a further movement has been communicated to the valve spindle V in the manner now well known, bringing the valves into the position shown in Figs. 31, 33, for the gas to enter the port Q^1 and expand the other bellows C^1, forcing out the gas in chamber A^1 through the port R^1, under the valve, by way of exhaust channel N^1 to the outlet O, and thus bringing the valves into the position shown on Figs. 26, 28, for another cycle to commence.

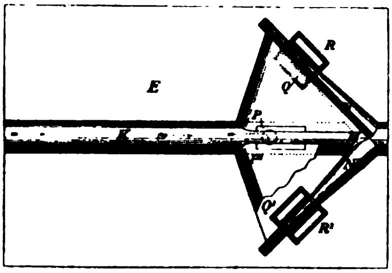

Fig. 35.

The crank V has now been revolved one complete turn, which turn is duly recorded by the index. It will now be clearly understood that the gas alternately enters and expands the bellows from the chamber H through a given port, and expels the gas in the chamber A through the other port, and the gas that previously entered the bellows is expelled back through the same port; but by reason of the movement of the valve, it is caused to pass away through the exhaust to the outlet, and this cycle is carried on continuously on either side—that is to say, it is equivalent to gas entering a cylinder at the forward side and forcing the piston along to expel gas previously entered at the back of the piston, and then by the change over of the valves the reverse takes place—the gas entering at the back of the piston to force the gas out at the front side, but in each case passing through the exhaust port to the consumer's pipes.

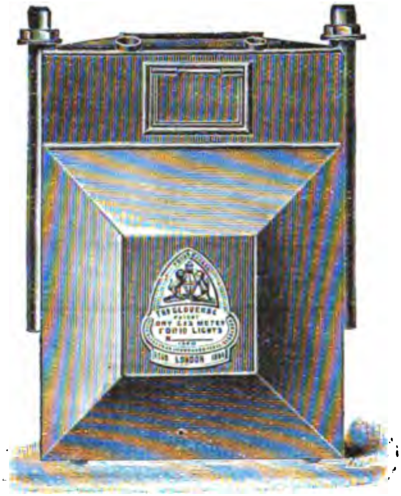

Fig. 36.

Now, inasmuch as the diaphragm D D^1 has a definite movement or stroke, and the area of the diaphragm is known, it follows that at each pulsation of the bellows a known cubical quantity of gas enters the bellows, and by the outward movement of the diaphragm a similar amount is displaced and passes away to the consumer's pipes, and by reason of the train of gearing being calculated to a given ratio of such outward movements of the bellows, a cubic foot is registered when a cubic foot has passed.

Moreover, should the meter by comparison with a standard meter be found to be either fast or slow, the stroke or amount of outward and inward movement of the diaphragm is regulated by shifting the tangent pin A nearer to or farther from the crank centre V, so the mechanism can be adjusted to give extremely accurate results, and yet, at the same time, the gas continually flows through the meter without interruption, because one of the valves being in advance of the other, one or other of the ports is always open before the other closes.

The bent wire *b* b^1 is hinged to pillars C C^1, and rides in slots of a plate attached at either side of the diaphragm to cause it to move out regularly, instead of unevenly, as would otherwise be the case. It should be noticed that, throughout the several views, the passages leading from the bellows to the parts of the slide valves are shown as pipes, to more clearly indicate the passage of the gas, and are, therefore, not to be taken as representing the actual construction of these passages as adopted in a meter.

As before explained, the valves are opened and shut by the motion of the diaphragms D D^1, with which they are connected by means of the flagwires T T^1, and the valves are so arranged that one of the chambers is receiving and the other discharging gas, so that the bellows are never both full or both empty at the same time; each chamber is distinct from the other, but they are connected together by the rods and top mechanism, so that one cannot move without the other.

The horizontal sliding motion of the valves is converted into a rotary motion for working the index, which consists of a very simple train of wheels and pinions (similar to those used for clockwork) and by hands or pointers adapted to move over a series of indices, by which the gas, as it is measured in its passage through the meter, is registered. The index shown at Fig. 37 is that usually attached to a ten-light meter, the small dial at the top having five divisions representing units, so that when the pointer has moved once round this dial it will indicate that five cubic feet have passed through the meter. Each of the other three indices are divided into ten, and are capable of recording from 100 to 100,000 cubic feet. The three lower dials are marked respectively 1 thous., 10 thous., 100 thous., indicating that when the hand of any one of these three dials has made a complete revolution, it will count as either 1000, 10,000, or 100,000 respectively, and it is not to be taken that when the hand has moved from 1 to 2 a thousand has passed, but only 100; therefore, the first dial represents in each division so many hundreds, the second dial so many thousands, and the third dial so many tens of thousands. For example, each division of the dial marked 1 thous. is equal to 100, and a complete revolution of the hand to 1000. Each division of the dial marked 10 thous. is equal to 1000, and a complete revolution of the hand, to 10,000. Each division of the dial marked 100 thous. is equal to 10,000, and a complete revolution, to 100,000.

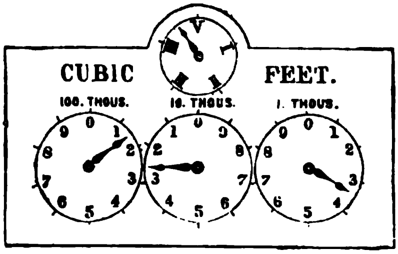

Fig. 37.

In reading the index of a meter it must be remembered that two ciphers (00) are always understood to be placed at the right of the figures on the dial marked 1 thous., so that 1, 2, 3, denote 100, 200, 300, and so on to 900. When the hand upon the 1 thous. dial has completed a revolution and points towards 0, the hand on the centre dial will have moved from 0 to 1. Three ciphers (000) have then to be added to these figures, making, with the 1 just mentioned, 1000. The same method of decimal computation applies to the left-hand dial; the first figure denoting 10,000, the second 20,000, and so on until the pointer has gone round to 0, when the total quantity of gas recorded will be 100,000. It must be remembered that the pointers on the outside dials move from left to right in the same direction as the hands of a watch. The pointer on the centre dial moves from right to left. This is done to simplify the mechanism and prevent unnecessary friction. As examples of the method of ascertaining from time to time the quantities of gas consumed, and of keeping a record of the same, the following instructions should be followed:— The figures must be read in their proper order of units, tens, and hundreds, beginning with hundreds, which, of course, is the first figure at the left-hand, and being careful always to take the figure next behind, never in advance of, the pointer. Thus, in Fig. 37, the state of the index is 1, 2, 3, which is immediately made intelligible by the addition of two ciphers (as before explained), the quantity of gas registered being 12,300 (twelve thousand and three hundred) cubic feet. After a few weeks or months, according to the number of burners and the season of the year, on again examining the index we will suppose the figures to be as shown in Fig. 38, namely, 1, 4, 9, which, by the addition of two ciphers, become 14,900. If from these we deduct the former 12,300, the gas consumed will have been 2600 since the previous inspection.

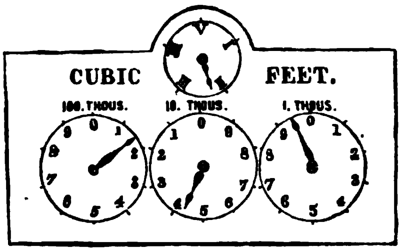

Fig 38.

Let it be noticed that, although the hand upon either of the dials may, as in the case last mentioned, point towards any one of the figures, that particular figure will not be the correct indication unless the hand upon the dial immediately to the right has completed its revolution. In this respect the same rule must be observed as with clocks and watches. Supposing the hour hand to point towards 2 and the minute hand towards 11, it would not be correct to say it was 2 o'clock. In the present case, the hand on the centre dial points towards 5, and that on the right-hand dial between 9 and 0; but, as the latter has not arrived at 0 the record is not 15,000, but, as already stated, the figures next behind the pointers must be taken down, namely, 14,900, or more exactly, 14,950.

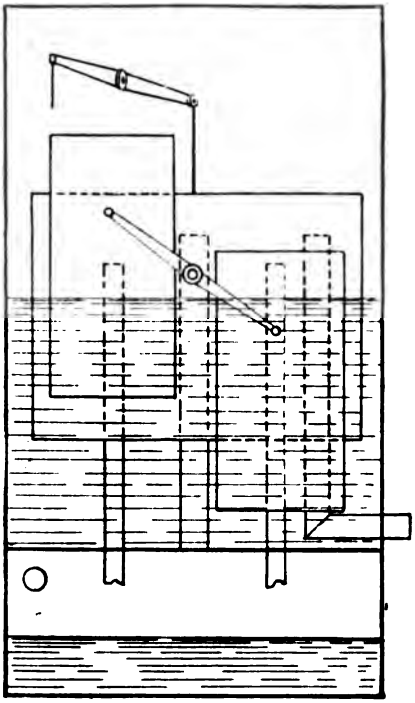

Fig. 39.

The Wet Meter.—There is no doubt that this meter originated from the mode in which gas makers timed the rising and falling of their gasholders. They were in those days in the habit of marking a scale up the side of the holder, and by taking into account the fact that during the day gas was being made and little consumption taking place, and that at night little gas was manufactured and the consumption was at its greatest, they were enabled to get an approximate idea of their manufacture and consumption.

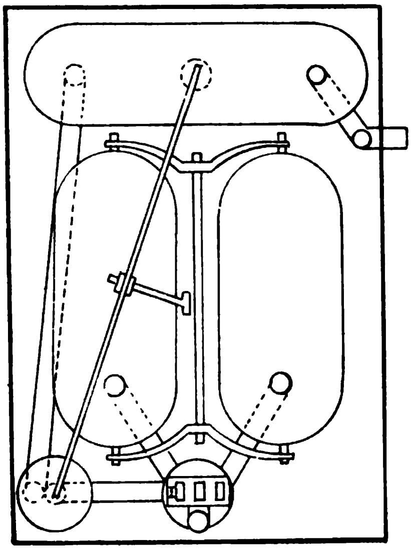

Fig. 40.

Figs. 39 and 40 show an early form of what might be termed a holder-meter. The twin bells worked up and down alternately, and, by a lever attached to them, a slide valve was moved, which allowed the entrance of gas into and out of the valves.

One of the first drum meters made is shown in Fig. 41. It has two chambers. The gas enters in through the spindle, passes into the chambers through the syphon pipes and the outlet, which is a small hole on the outside of the drum, to the outlet of the meter.

Figs. 42 and 43 illustrate one of the first meters having a four-partition drum. In this case the gas enters into a centre chamber of the drum by means of a spout. From this inner chamber it enters into the measuring chambers through a slit, and as it revolves, escapes through another opening at the top.

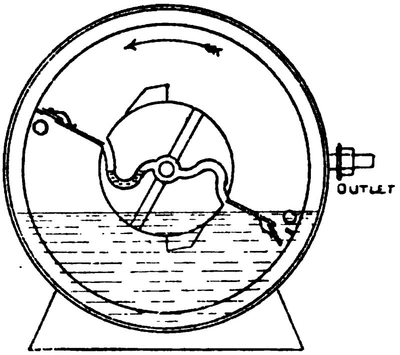

Fig. 41.

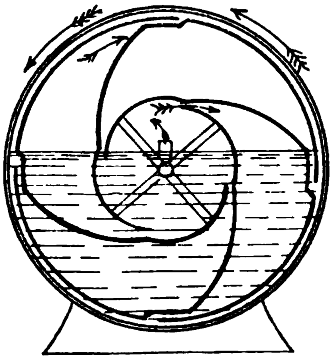

Fig. 42.

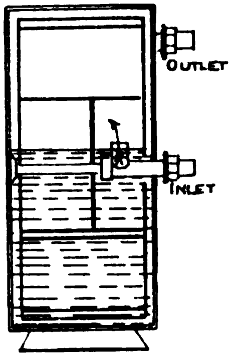

Fig. 43.

The meter shown in Fig. 44 may be taken as the standard pattern now in general use. The only addition or variance from this meter is an attachment to counteract, or counterpoise, the evaporation of water—a defect which none of the former meters had overcome. In this meter the gas enters through the casing of the meter by an elbow pipe into the drum. This drum revolves on its shaft, and is divided into four distinct chambers as shown in

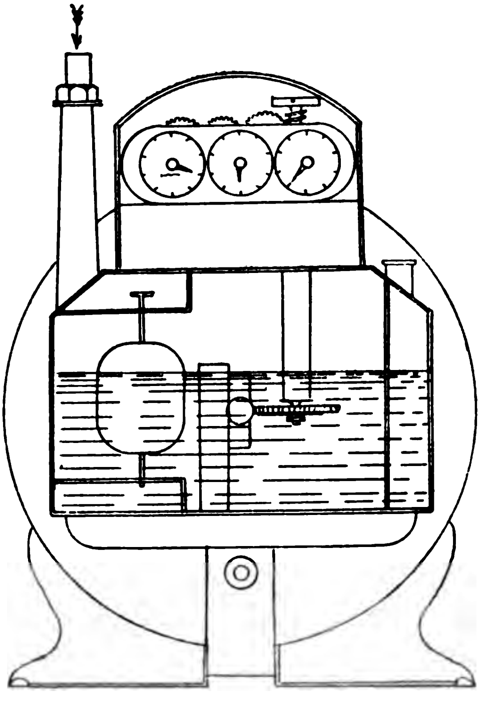

Fig. 44.

Fig. 45, which also shows one of the four parts with its sloping partitions. Figs. 46 to 49 give the other divisions of the drum, back, front, and top, together with one section out of the water-line. The action of the meter is shown in Fig. 50. On the back of the drum is a hood-piece, covering up the four openings of the different chambers. The hood is kept supplied with gas by the spout, which is really a continuation of the company's main. As the opening of the drum at the back is above the water-line the gas enters underneath one of the chambers and presses it forward until the opening dips into the water on the reverse side, enclosing a certain quantity of gas, dependent upon the height of the water-line. By the time that this movement has taken place, the second chamber shows an opening, and takes up the work of its predecessor, and so on until each chamber has done its work in rotation. The gas in the chambers is allowed to escape by an opening or slit in the front of the drum to the outlet of the meter.

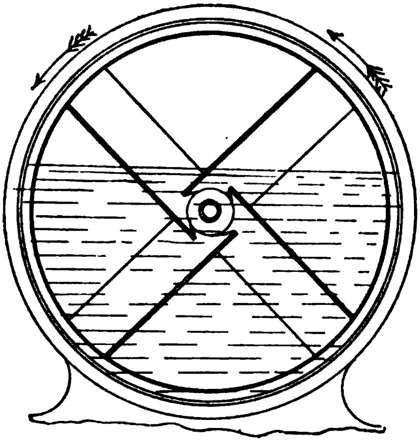

Fig 45.

Fig. 50 is the form of meter made for large consumers, or station meters, and is supplied with a small stream of water flowing into it, the surplus water being allowed to escape through a suitable draw-off plug. In smaller meters a float arrangement is fixed—see Fig. 44. This float is allowed a certain margin of water-line, and when the meter is not continually being refilled it drops down and shuts off the supply of gas. But most companies

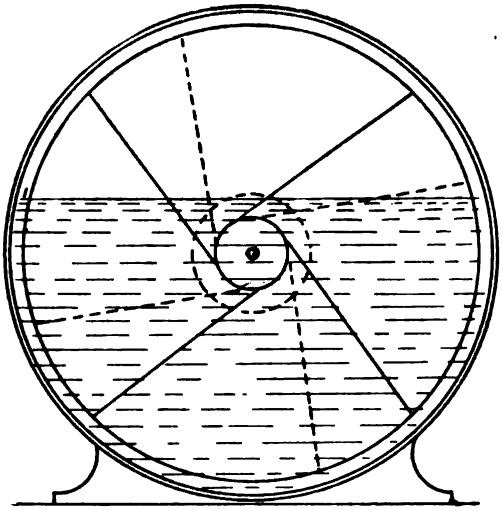

Fig. 46.

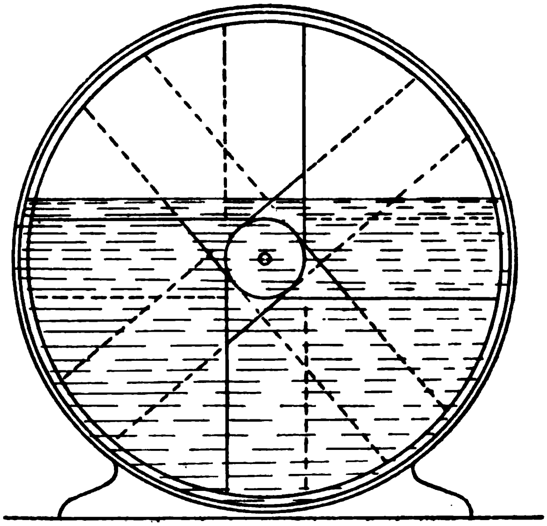

Fig 47

now insist upon having some sort of compensating arrangement fitted to their meters, which keeps the water-line at a fixed level. There are also some meters fitted with compensating drums, which return a certain amount of gas at each revolution.

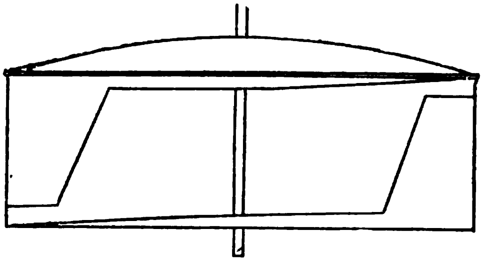

Fig. 48.

The advantage of the dry meter over the wet one for ordinary use is that it does not require constant attendance in order to supply water, although at times it may be necessary to empty out water condensed from the moisture

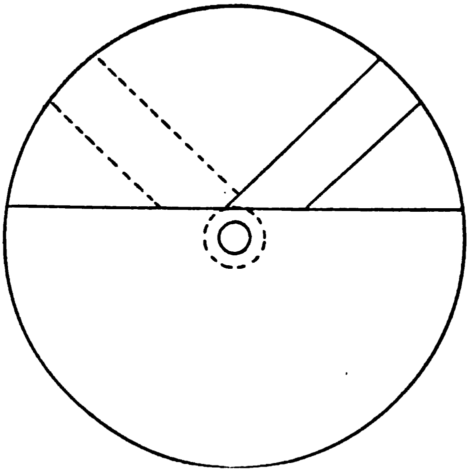

Fig. 49

carried by the gas. Unfortunately, however, in consequence of the variation of the foldings of the leather portion of the bellows, the indications of a dry meter are not so perfect as may be obtained from a wet meter, the water-line in which can be adjusted with perfect accuracy, and therefore the wet meter is always preferred for experimental measurements of the volume of a gas used in testing either its quality or that of any special burner employed for its consumption.

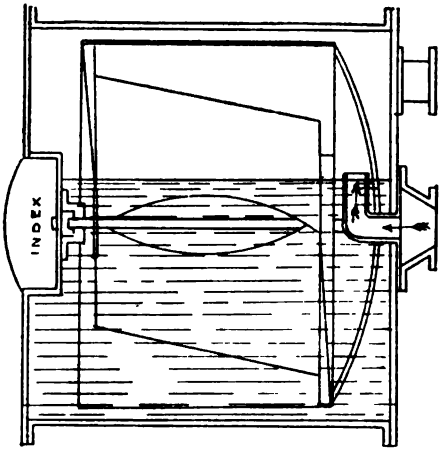

Fig 50.

Prepayment Meters.—The dry form of meter is almost exclusively used for the prepayment, or penny-in-the-slot, meter. This new feature in the gas industry, although it is quite in its infancy, has already been found to be a great boon to the working and middle classes. It has the great advantage that consumers know exactly the cost of their gas lighting and cooking, and can tell day by day what their expenditure is in this direction. Most of the prepayments attachments are connected with a worm and wheel (see Fig. 34 at spur wheel G) to the ordinary meter, and with each revolution of the meter this is transferred to a reciprocating motion, which is driven in one direction by the meter's working, whilst, by the insertion of a coin into a moving money pocket, the reciprocating motion is driven back in the opposite direction. Attached to the moving part of this reciprocating motion is an arm or lever working a valve. When the mechanism is actuated by a coin it opens a valve and indicates on a small dial the amount of gas paid for. A limited number of coins may be inserted into the meter before it is full. As the gas is used the mechanism draws back the lever controlling the valve until the full quantity of gas has been consumed. Another important part of this mechanism is that it can be set to give a certain number of cubic feet of gas for each coin inserted. This is done by two methods. First, by a movable price-changer, which can be moved very easily to the required number of feet to suit the price of gas sold in the district. Second, by a system of change wheels.

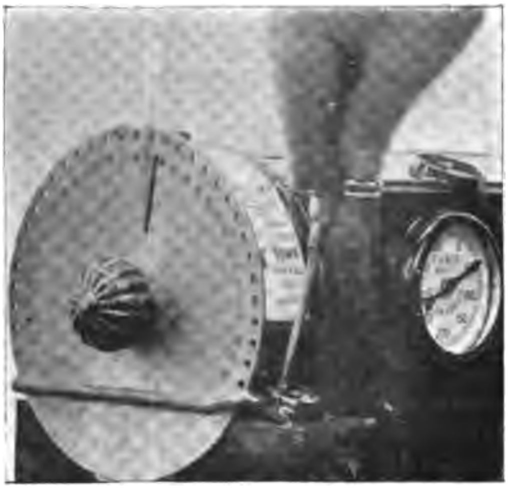

Fig. 51.

Messrs. T. Glover and Co.'s improved prepayment meter.—The price-changing device of this firm is claimed to be a

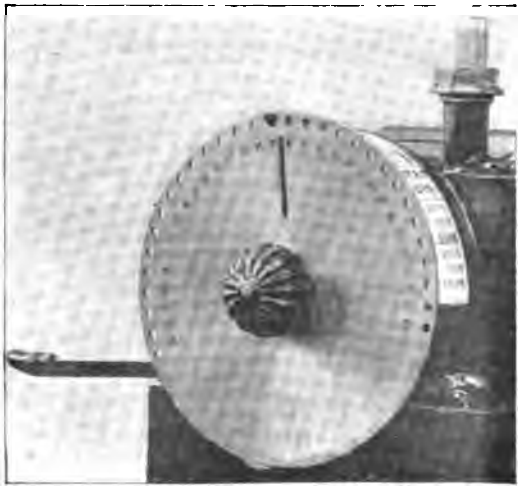

Fig. 52.

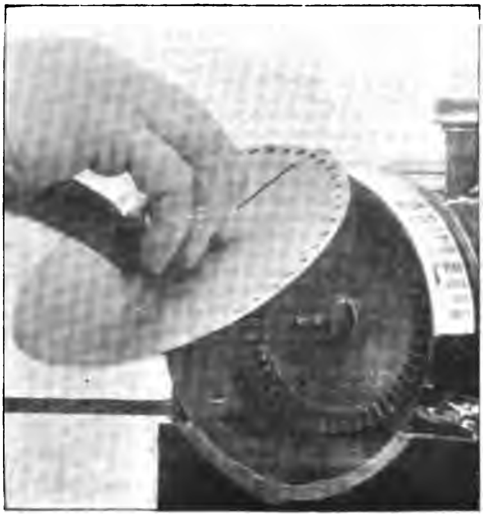

Fig. 53.

gem of mechanical ingenuity. It consists of a brass plate having holes around its edge, numbered by regular intervals and indicating the number of feet to be delivered for the coin. This plate is suspended from a hook through the proper hole, and is fastened to the meter by a cross-bar, locking screw, and seal. Access to this screw can only be obtained by breaking the seal. The removal of the screw permits the plate to be hung by any desired hole, when the quantity of gas to be delivered for the coin is at once varied. There are no gears to be changed. No tools are necessary but an ordinary screw-driver. The price of gas at which the meter is set can be determined at a glance at any time (Figs. 51 to 54).

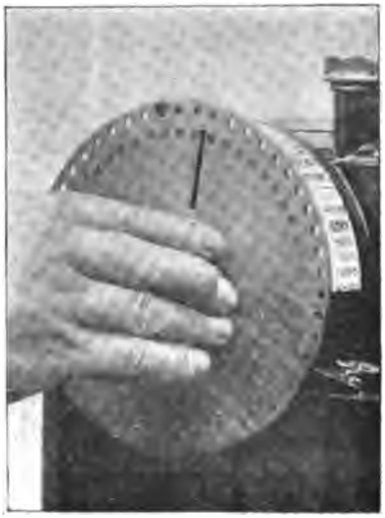

Fig. 54.

Messrs. W. Parkinson and Co.'s ordinary wet meters in cast iron cases (Fig. 55) work with very little friction, and are constructed to stand very high pressures. They cannot possibly be shut off by sudden increase of pressure, the float being affected by outlet gas only. They allow for loss of

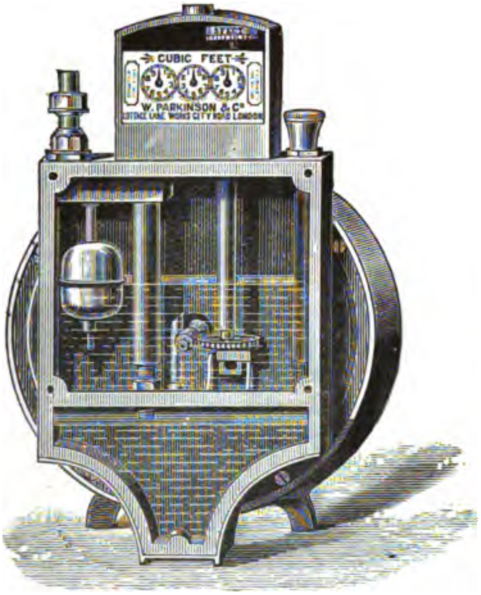
CUBIC FEET
W. PARKINSON & Co
COTTAGE LANE WORKS CITY ROAD LONDON

Fig. 55.

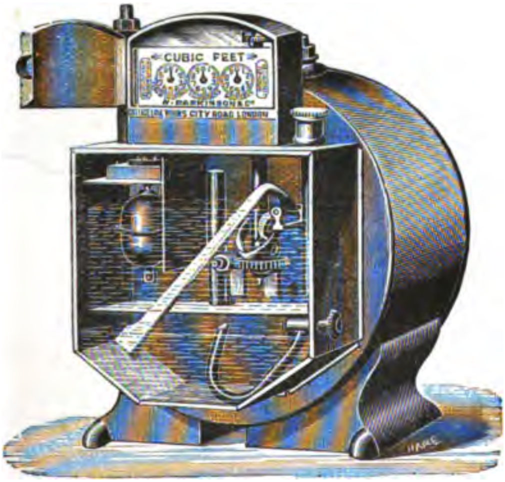
CUBIC FEET
W. PARKINSON & Co
COTTAGE LANE WORKS CITY ROAD LONDON

Fig. 56.

water by evaporation, without materially affecting the registration or shutting off the gas.

The same firm supplies compensating meters in tinned or cast iron cases (Fig. 56). This form of slow-spoon compensator has been in extensive use for many years; it maintains an unvarying water-line without appreciable friction, and provides a large reserve of water. The float arrangement allows sudden or excessive pressure on the inlet without affecting the working of the meter or extinguishing the lights.

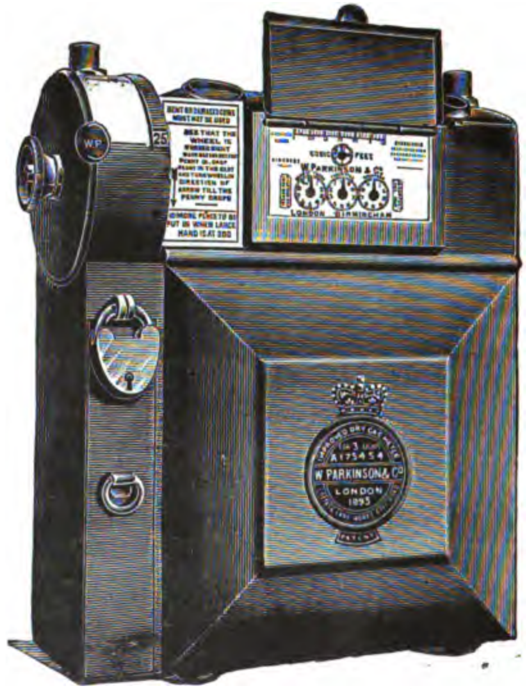

Fig. 57.

The following instructions are given by Messrs. W. Parkinson and Co. for using their prepayment meters :—

Directions.—Turn the wheel at the side of the meter

(Figs. 57 and 58) right back and put the coin in; then turn the wheel forward until the coin drops in the box below.

For altering the price at which the gas is sold.—Break the seal at the front of the side box, remove the screw, and turn the numbered brass scale until the required number appears;

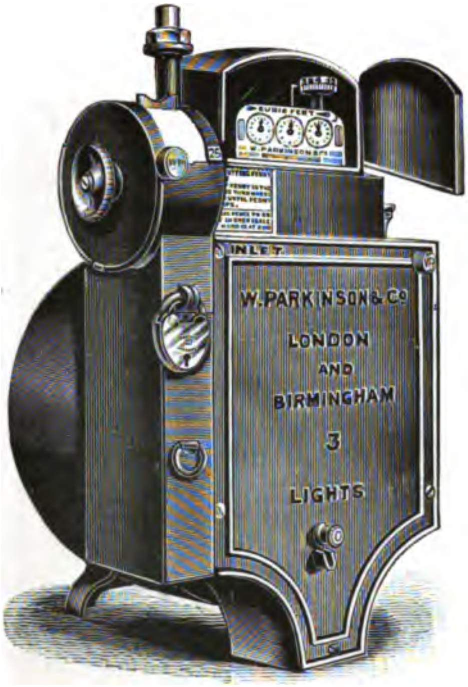

Fig. 58.

then secure the scale by inserting the screw again, and seal if desired. The numbers on scale indicate the quantity of gas in cubic feet given for each coin.

Should the meter be tampered with, or any foreign substance be forced into the slot, the inspector can readily see what is wrong by taking out the screw above referred to, and removing the side of the box, which is fitted with a simple bayonet joint.

The Sutherland Patent Automatic Attachment (see Figs. 59 and 60) is claimed to be one of the most simple that has yet been placed on the market. All the parts are interchangeable, and may be instantly replaced. All screws are of Whitworth standard sizes, and special attention is called to the auto-valve, which is not affected by condensation or grit. With the aid of a screw-driver the inspector can instantly adjust the number of feet of gas to be supplied. The price-changing mechanism can only be adjusted by the inspector. These meters can be made for shillings or any other coin.

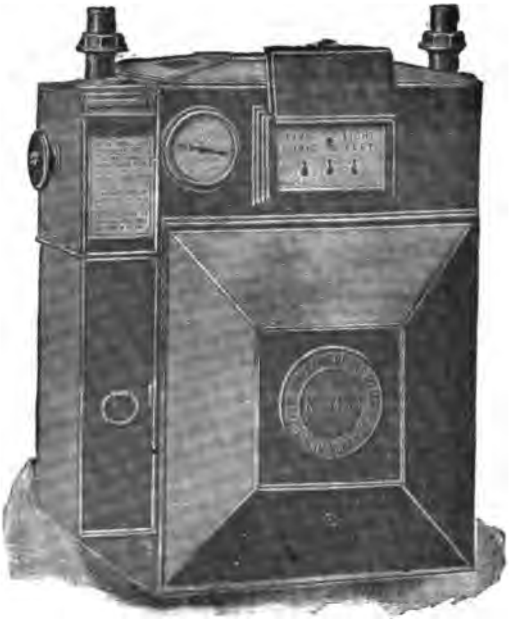

Fig. 59.

Messrs. W. B. Cowan and Co.'s Prepayment Gas Meters (Figs. 61 and 62).—The convenience and advantages inherent in the pointer and scale principle of price adjustment have been rendered certain of attainment by providing a series of numbered holes, into any one of which the screw which secures the pointer may be fixed. Thus any possible uncertainty in regard to the setting of the pointer is prevented. The coin itself operates the prepayment wheel when gas is being purchased; and the coin is not discharged into the money-box till its full value in gas has been placed at the consumer's disposal. The discharge of the coin is effected by the pointer itself, which carries a cam that acts on the coin and ejects it when gas equal in quantity to that which the pointer indicates has been made available—but not before.

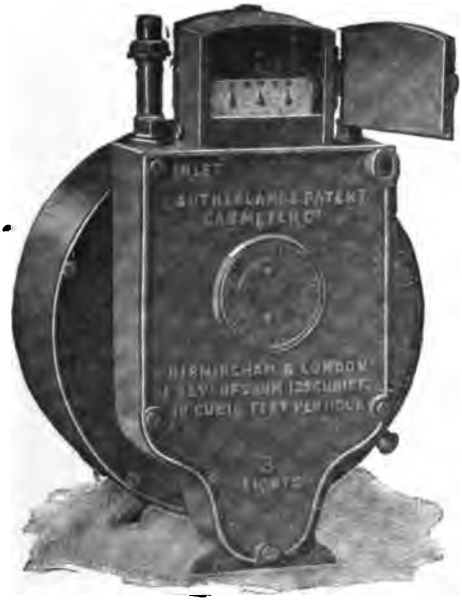

Fig. 60.

It is claimed that meters constructed on the change-wheel system possess important advantages over other coin meters of the same type; the mechanism being simpler and less liable to derangement than that of any similar meter in the market.

When the mechanism has to be re-adjusted to suit changes in the price of gas, this is effected by removing two wheels, and replacing them by others having the number of teeth required to give the exact quantity of gas desired. This interchange is readily performed, the mechanism being so arranged that the removal of a single pin or screw enables the wheels to be withdrawn and replaced, without serious trouble or loss of time. In a meter of this type this is a matter of great importance, especially where large numbers of prepayment meters have to be re-adjusted to suit alterations in the price of gas.

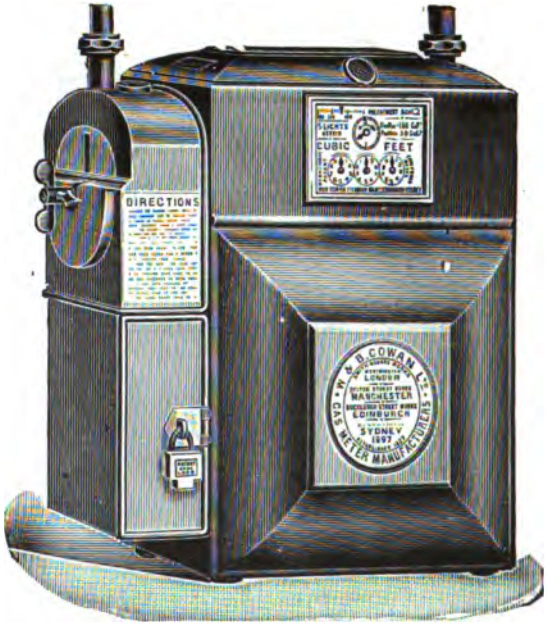

Fig. 61.

Simmance's Patent Double-coin Meter (Fig. 63).—The mechanism of this enables coins of two or more different values to be used in the one meter. The usual coins are a shilling or a penny, and any number up to 24 can be inserted in any order, and gas given in exact proportion. A separate slot is arranged for each kind of coin which must be of different dimensions, and a small coin placed in a larger slot will be automatically rejected. In the case of a shilling and a penny, if a shilling is inserted, and gas commences to pass, and then a penny be inserted, the presence of the penny throws the shilling action out of gear until a separate pennyworth has been delivered, after which the unworked-off balance of the shilling will be yielded.

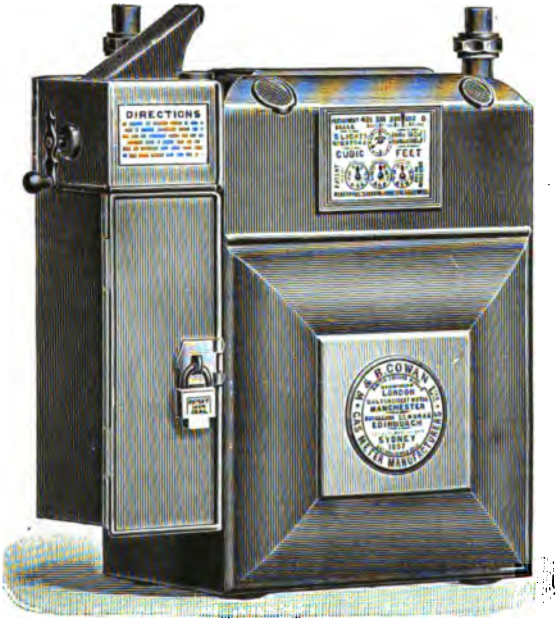

Fig. 62.

The accuracy of all gas meters supplied to the public is guaranteed by the system of testing prescribed by the Sales of Gas Act, 1859. Under this Act, Justices of the Peace, County Councils, and Town Councils may appoint Inspectors and provide them with the necessary apparatus for the testing of gas meters, which, having been found correct, are stamped with a stamp issued by the Standards Department of the Board of Trade, and any person using a meter not so stamped is liable to a fine of £5. It is specially provided in the Act that no maker, repairer, or seller of meters, or of gas, or person so employed, shall be an Inspector of Meters under the Act. The following points are specifically referred to in the Act:—"Clause XII.—No meter shall be stamped which shall be found by the Inspector to register, or be capable of being made by any contrivance for that purpose, or by increase or by

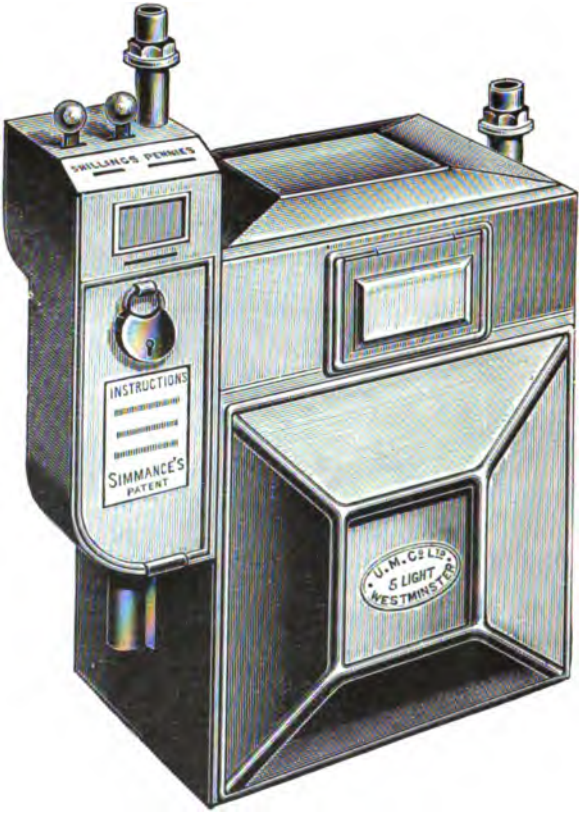

Fig. 63.

decrease of the water in such meter, or by any other means practically prevented in good meters, to register quantities varying from the true standard measure of gas more than two *per centum* in favour of the seller, or three *per centum* in favour of the consumer; and every meter, whether stamped or unstamped, which shall be found by such Inspector to register or be so capable of being made to register quantities varying beyond the above limits aforesaid, shall be deemed incorrect within the meaning of this Act. Provided always that every meter having a measuring capacity at one revolution or complete action of the meter of not less than 5 cubic feet, and having permanently marked upon it in some conspicuous place the words 'without float,' shall be stamped by the Inspectors if found correct."

This last provision applies to large station meters used for special purposes only.

"Clause XIII.—The following rules shall be observed by the Inspector in testing meters under the provisions of this Act:—

"Firstly, the meters shall be tested for soundness or leakage only, and not for percentage of error, when fixed on a horizontal base, and with gas under a pressure equal to a column of water three inches high, with a light or lights consuming not more that one-twentieth part of its measuring capacity per hour marked thereon, nor less than one-half of a cubic foot per hour, for all meters of a measuring capacity not exceeding one hundred cubic feet per hour, and not more than one-fortieth part of its said measuring capacity per hour for all meters of any greater measuring capacity per hour than one hundred cubic feet; and all meters found to work under such test shall be deemed sound meters, and any meter found not to work under such test shall not be stamped."

"The meter to be tested for percentage of error shall be fixed on a horizontal base, and shall be tested at a pressure equal to a column of water five-tenths of an inch high, and passing the quantity of gas or atmospheric air per hour, which shall be marked thereon as its measuring capacity per hour, and the water used in such testing, and the air in the room in which such testing shall be made, shall be as nearly as practicable of the same temperature of the gas or air passed through the meter."

"Clause XIV.—If any person or persons shall make, except under the authority of this Act, or forge, or counterfeit, or cause or procure to be made, except as aforesaid, or forged or counterfeited, or knowingly act or assist in the making, except as aforesaid, or forging, or counterfeiting, any stamp or mark which may be hereafter used for the stamping or marking of any meter under this Act, every person so offending shall for every such offence forfeit on conviction a sum not exceeding fifty pounds or less than ten pounds; and if any person shall knowingly sell, utter, or dispose of, let, lend, or expose to sale, any meter with such forged stamp thereon, every person so offending shall for every such offence forfeit on conviction a sum not exceeding ten pounds or less than forty shillings, and all such meters with such forged and counterfeited stamps shall be forfeited and destroyed."

Clause XV. enacts a penalty of five pounds against any person who shall alter or tamper with any stamped meter so as to cause it to register unjustly or fraudulently, &c.

Clause XIX.—"The fees for examination, comparison, and testing, with or without stamping, meters, shall be sixpence for each meter delivering a cubic foot of gas in four or more revolutions or complete repetitions of the action of the meter, and one shilling for each meter delivering a cubic foot of gas by any less number of revolutions or complete actions, or one revolution or complete action; and for each meter delivering more than one cubic foot of gas by one revolution or complete action, the further sum of one shilling for every cubic foot of gas delivered at one revolution or complete action beyond the first cubic foot."

Clause XX.—"In England and in such boroughs and towns as aforesaid in Ireland, it shall be lawful for any Inspector, authorised in writing under the hand of any Justice of the Peace in England and Ireland, or of any Sheriff, Justice, or Magistrate in Scotland, at the request and expense of any buyer or seller of gas, who shall have given twenty-four hours' notice in writing to the other party to the contract, at all reasonable times to enter any house or shop, store, warehouse, shed, yard, or place whatsoever within his jurisdiction, where any meter, whether stamped or unstamped, shall be fixed or used, and to examine and test the same, and, if necessary for such purpose, to remove such meter, doing as little damage thereby as may be; and if upon such examination and testing it shall appear that any such meter is incorrect within the meaning of this Act, or fraudulent, the same shall not be refixed or used again unless and until altered and repaired so as to measure and register correctly, and stamped; and the fees on such removal, examination, and testing of a meter, whether stamped and replaced or not, shall be double the fees hereinbefore made payable for testing and stamping, and shall be payable by the buyer or seller of gas as the Justice of the Peace in England and Ireland, or the Sheriff, Justice, or Magistrate in Scotland, as the case may be, shall determine, and shall be recoverable accordingly; provided always, that in case the head office of the person or company to whom such notice is to be given shall be more than twenty miles distant from the meter referred to in such notice, three days' notice in writing shall be given instead of twenty-four hours' notice as aforesaid; and provided also, that any person duly authorised by any company or person selling gas by meter may supply water to any meter, so as to keep the water at the correct level."

Clause XXI. provides for disputes between the parties as to the correctness of a test.

The remaining clauses of this valuable Act are merely administrative, and need not here be further referred to.

From the foregoing it will be seen how carefully the interests of the consumers are guarded. If those who so loudly complain of the inaccuracy of their gas meters would only take the trouble to ascertain the facts of the case, they would soon be more than satisfied of the manner in which every exertion is made to ensure rigid accuracy in the measurement of the gas they use. In London alone about a quarter of a million meters are tested annually at the gas meter testing stations formerly instituted by the Metropolitan Board of Works, and now under the control of the London County Council, where a large staff of highly-trained and thoroughly independent Chief Inspectors, Inspectors, and assistants, are daily employed in this duty alone.

There is one point, however, about the ordinary consumer's gas meter which, in very few exceptional instances, renders the indications unreliable, and that is that by some oversight in fitting the train of wheels, actuating the dial hands, a wrong one may be used, that is to say, one of a set belonging to a meter of different size may be accidentally placed in position. This will cause an error so large that sooner or later it is sure to be detected. Unfortunately, the law does not provide for the independent testing of the indices, and as the usual test of a meter relates only to the correctness of the capacity of the measuring drum in a wet, or bellows in a dry meter, as the case may be, and the quantity of gas passed through the meter being only some 5ft. or 10ft., there is no check upon the indications of the dials registering hundreds and thousands of feet.

This question has been again and again brought forward, and recommendations made for an alteration of the law in this respect so as to provide for the necessary testing, but without result. So far back as February, 1884, the writer reported fully on this matter to the Special Purposes and Sanitary Committee of the late Metropolitan Board of Works, who urged the necessity for the amendment of the Act upon the Government authorities, but in the press of parliamentary work no time could be found for action, although its desirability was admitted.

The Inspectors and their assistants do detect a number of such cases in the course of their ordinary work, as they are fully alive to the matter; but the question will not be properly settled until the indices are separately tested and stamped.

The following observations of the Inspectors on some of the cases detected by them will serve to indicate the nature of the fault* :—

"Wrong wheel on dial indicating tens of thousands of feet, whereby that hand loses 65,000 in every million. The index is further defective, whereby the 100,000 hand occasionally indicates 200,000."

"Defect in frame of index, the hand indicating hundreds would not register, the next dial indicating 5000ft. for each 100ft. passed through the meter."

"Error in consequence of hands coming in contact."

"The wheel on spindle of thousands did not gear in piston of hundreds; thousands hand did not register."

"Wrong index."

"Wrong driving wheel."

"Index works backwards; when 1000ft. passed, shows registration of 9000."

"Index did not register."

"Index registers double."

"Registers 20ft. for 10ft."

"Wrong drum."

"Third dial 52 teeth instead of 60. Index showed 33 per cent. against consumer."

As stated above, these are entirely exceptional; but, nevertheless, they should be guarded against, and not left to chance discovery.

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* Report of the Chemist of the Metropolitan Board of Works on "Defective Indices in Gas Meters," February 26th, 1884.

CHAPTER XI.

GAS BURNERS.

THE gradual development of the gas burner forms a most interesting study. At first the simple jet was employed, and then this was modified in various ways. It was not long before the advantage of arranging the jets in a circle, so as to produce a flame on Argand's principle, was adopted. The flat flame was first obtained by utilising the effect of two jets of flame impinging upon one another, with the result that the mutual resistance of the two currents of gas caused a lateral expansion. This arrangement is known as the "Fishtail" burner, because of the shape of the flame. For the same reason the "Batswing" was so named. This flame is obtained by causing the gas to leave the burner by an opening in the form of a slit. When the pressure of the gas is high the flame expands laterally to a considerable extent, hence the name "Batswing."

These original simple forms of burners were the forerunners of all the present developments of ordinary gas burners. The introduction of the principle of "regeneration" by Siemens, however, caused a complete revolution, and results were obtained which previously had been looked upon as beyond reach. Under the ordinary conditions anything from two to three candles of light yielded per cubic foot of gas consumed was considered good, but Siemens at once raised this "duty," as it is called, to four and five candles per foot. The original burners of Siemens were constructed on the principle of the Argand, but the flame turned down inwards over the edge of a short earthenware chimney placed in the centre of the flame, by which arrangement the heated products of combustion were caused to warm both the gas and air supplied to the burner, with the result that the light thereby obtained was considerably enhanced.

Mr. Grimston then conceived the idea of turning the burner upside down, so that the bottom portion should not cast a shadow, and this he carried out very effectually. Mr. F. W. Clark produced a smaller type of lamp on the same principle, but particularly adapted for use in railway carriages. Then followed the well-known Wenham lamp, and others of more or less value, until Mr. Sugg finally produced a burner on this principle which gave a duty of 11 candles per foot.

These great improvements, worked out by indefatigable inventors after years of patient labour, were nevertheless thrown completely into the shade by the almost overpowering light yielded by means of the inventions of Herr von Welsbach, whose incandescent " mantle," when in its best condition, readily yields no less than a " duty " of 20 candles per foot, without the use of forced air or gas. By means of such contrivances even better results are obtained, and it yet remains to be seen where finality will be reached.

As many people yet prefer to employ the older patterns of gas burners, it will be advisable to consider these and the results they give somewhat more in detail.

A most complete investigation of the light-giving values of various forms of gas burners then available to the public was undertaken by the author in conjunction with the late Professor William Foster, at the request of the Committee of the Gas Section of the Crystal Palace Electric Exhibition in 1882-3. This work has been supplemented from time to time by the author, and the results embodied in the present chapter.

Single Flat-flame Burners without Governors. — The results of numerous tests show conclusively the great loss of illuminating power occasioned by the use of union jet and iron jet burners, the highest duty afforded by the union jet when burning 16-candle gas being 2·7 candles per cubic foot of gas consumed, and only 2·1 by the iron jet. In this series the superiority of the various types of steatite slit burners is very marked, the duty rising to a maximum of 3·2 candles per foot of gas. When the consumption of gas varied from 1·0 to 3·0 cubic feet per hour, the duty varied with different burners from 0·9 to 2·2; with consumptions from 3·1 to 4·0 cubic feet per hour, the duty was from 1·0 to 1·6; with consumptions from 4·1 to 5·0 cubic feet per hour, the duty was from 1·2 to 2·1; with consumptions from 5·1 to 6·0 cubic feet per hour, the duty was from 1·8 to 2·8; with from 5·1 to 6·0 cubic feet per hour, the duty was from 1·9 to 2·8; with 6·1 to 7·0 cubic feet per hour, it was from 2·4 to 3·0; and over 7·1 cubic feet per hour, the duty varied from 2·0 to 3·2.

It will thus be seen that, apart from the particular burner employed, there was an increase in the quantity of light yielded per cubic foot of gas consumed up to a maximum of 3·2 candles of light per cubic foot of gas, and it would seem that this is the limit which can be reached by ordinary single flat-flame burners. If the quantity of gas forced through the burner exceeds the limit for which the burner is constructed, either a loose smoky flame, or one overburnt, after the manner of a blow-pipe flame, results. In either case the quantity of light per unit volume of gas is at once reduced, and loss results.

In 1871 the Metropolitan Gas Referees reported fully upon the question of the construction of gas burners with reference to the principles of gas illumination. The information embodied therein is so valuable and interesting that the following extracts are reprinted, as forming one of the most important links in the chain of knowledge of the practical application of illuminating gas for lighting purposes.

EXTRACTS FROM THE FIRST REPORT TO THE BOARD OF TRADE BY THE GAS REFEREES ON THE CONSTRUCTION OF GAS BURNERS WITH REFERENCE TO THE PRINCIPLES OF GAS ILLUMINATION.

To the Lords of the Committee of Privy Council for Trade.

Gas Referees' Department, 28, New Street,
Spring Gardens, June 22nd, 1871.

The Gas Referees have the honour to submit to the Board of Trade the following Report, which contains the result of their investigations of the principles which regulate the development of light from gas, and the application of those principles to the construction and use of burners, in the manner most advantageous and economical for the public.

Every improvement in the construction of gas burners is equivalent, in its economical effects, to the discovery of a method of cheapening the manufacture and supply of gas; for it enables the public to obtain more light from the gas which they consume and pay for. By using good burners, instead of bad ones, consumers may obtain from 30 to 50 per cent. more light, while their gas bill remains the same.

The improvement of burners is also important as a measure of sanitary reform; for as by this means the required amount of light is obtainable from a smaller quantity of gas, the atmosphere of rooms and workshops is less vitiated. Not only is an unnecessary amount of heat avoided, but, in consequence of less gas being burnt, the pernicious products of combustion discharged into the air (viz., carbonic acid gas, the sulphur impurities, &c.) are equally diminished; so that the condition of the occupants of private dwellings, and still more of the workpeople employed in factories and other large establishments, is rendered more comfortable and healthy than it could otherwise be. In fact, the improvement of burners is itself an important means of diminishing the pernicious effect of the impurities in gas—the gradual reduction of which impurities to a minimum is one of the duties devolved upon the Gas Referees.

As stated in their Report, dated 3rd May, 1869, the Referees, in the course of their investigations relative to the choice of a standard burner, made and tested a large collection of burners of all kinds, obtained from the leading gas-fitting establishments and other quarters; and in consequence of the great numerical preponderance of bad burners in the collection, they were led to inspect the gas-lighting arrangements in several large establishments in the City—especially those in which, owing to the prevalence of night-work, an unusually large quantity of gas is consumed. The inspection fully confirmed the apprehensions which the Referees had formed from their examination of the burners procured from the gas-fitting establishments. For example, in the offices of two of the daily newspapers (establishments which consume more gas than any others), it was found that the burners chiefly in use were so defective that they gave out only *one-half* of the illuminating power of the gas actually consumed. And several of the burners tested by the Referees gave only *one-fourth* of the proper light of the gas! These facts, and many others which came to their knowledge, proved to the Referees that "an enormous waste of gas prevails, with a corresponding pecuniary loss to the public;" and they considered it a matter of urgent importance that such facts should be made generally known.

The economy to the public, arising from the use of good gas burners instead of bad ones, is so obvious as hardly to need remark. The gas rental of London amounts annually to more than *two millions sterling.* Taking a very moderate estimate, upwards of *one-fourth* of this sum (£500,000 per annum) might be saved by the use of good burners. This is the saving which might be made in London alone; how much vaster the sum thus economised if good gas burners were to come into general use throughout England! In truth, the economy arising to the public from the use of improved burners is as large as can be produced for many years to come from any improvements in the manufacture of gas, or from the amalgamation of companies by which the cost of supply will be so materially reduced. The question of burners, indeed, although hitherto so little considered or investigated, meets one at every turn in matters connected with gas-light—whether these be regarded as problems of science, or in the more widely useful and practical form as a means of economy for the gas-consuming public.

On the Illuminating Power of Gas.—As a scientific question, the illuminating power of gas has given rise to much discussion; and there are several points of this kind, which, owing to their practical bearing, must be determined at the outset, in any satisfactory exposition of the most efficient and economical means and apparatus for obtaining a maximum of light from gas. The first of these questions is, Is the illuminating power affected by the quantity in which gas is burnt?—in other words, Is it more economical to use small burners or large ones?

The doctrine that the light-giving power of gas undergoes variations according to the quantity in which the gas is burnt was first propounded, as the result of experiments, by Drs. Christison and Turner, of Edinburgh, in 1825, and subsequently by the late eminent gas engineer, Mr. King, of Liverpool, by MM. Audoin and Bérard, of Paris, and others, all of whom maintain that gas gives a larger proportion of light when it is burnt in large quantities than in small. The most recent experimentalist upon this question is Mr. Farmer, of America, photometric observer to the Manhattan Gas Company, who holds that the illuminating power of gas increases in a geometrical ratio as the square of the quantity of gas consumed. According to this doctrine (now known as the "Farmer Theorem")* if 2ft. of gas give a light equal to 4, 3ft. of the same gas will give a light equal to (not 6, but) 9—4ft. to 16—5ft. to 25—and 6ft. will give a light equal to (not 12, but) 36. Although this theorem appears to have been accepted in America, it has found no supporters in this country. Nevertheless, the doctrine that the illuminating power of gas *does* vary (although in what ratio is not agreed) according to the quantity of gas consumed appears to have taken firm ground on the Continent, as well as in this country, and in America. As a practical question, it is important to determine whether the doctrine is correct.

In a case like this, the first and most natural suggestion is, to inquire whether the observed variations in the illuminating power are not due, wholly or in part, to the mechanical apparatus employed for developing it. If two tons of identically the same coal do not, when burnt separately, give out the same amount of heat, is not the explanation to be sought in some difference in the mode of combustion? If two gallons of the same water, when weighed separately, do not show the same weight, must there not be some difference in the balances, or in the details of weighing? In like manner, if 4ft. of gas do not give exactly two-thirds the amount of light which 6ft. of the same gas gives, is not the difference first to be looked for in the nature of the burners employed in the experiments? Not to take into careful account the influence of the burners, when testing the illuminating power of gas, is as great an oversight as if, in weighing, one were to make no examination of the balances; or as if an engineer were to take no account of the boilers he employed, and then, finding that a ton of coal in some circumstances raised a greater proportion of steam than when half-a-ton was used, were to jump to the conclusion that the heat-giving power of coal became greater, relatively to the quantity consumed, when a ton was used than when half that quantity was employed.

What a boiler is to coal and the generation of steam, so is a burner to gas and the development of light. One ton of coal in a locomotive of the present day generates as much force as six tons did forty years ago, simply owing to the superior construction of the locomotive. In like manner, as regards the illuminating power of gas, there are good burners and bad ones. Moreover, as every scientifically-constructed boiler is devised specially for a given amount of coal, by the consumption of which the boiler develops its maximum of power relative to the quantity of fuel used, so every well constructed burner is devised to consume a fixed quantity of gas. Indeed, for every burner, whether good or bad, there is a certain rate of consumption at which the burner does more justice to the illuminating power of the gas than at other rates, whether greater or less. To disregard these considerations is to render experiments wholly useless and misleading.

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* See page 140.

First, as to good burners and bad ones:—Take two burners, each of which gives its maximum of light (*i.e.*, does most justice to the gas) at the same rate of consumption; nevertheless the light emitted by one of the burners may be much greater, or much less, than that of the other. Secondly, as to the misuse of burners:—Take a burner which does most justice to the gas when the rate of consumption is 5ft. per hour; then, if the rate of consumption be either increased or diminished from that point, the gas will, of course, give out less light in proportion to the quantity consumed than before.

Both of these facts, simple as they are, seem for long never to have been even suspected. The early experimenters relative to the illuminating power of gas wholly overlooked this fundamental point in the inquiry. This error was committed by Drs. Christison and Turner, who hence came to the conclusion that because one Argand burning 4ft. an hour gave more light than two precisely similar Argands consuming 2ft. each, that therefore gas gave more light when burned in the former quantity than in the latter. Upon similar grounds these experimenters might have maintained that because a ball fired out of a rifle with a charge of 8 drs. of gunpowder went further and had more penetrating force than two smaller balls fired out of two similar rifles, each with 1¼ drs. charge, that therefore gunpowder had more explosive force, relative to its weight, when fired in the former quantity than in the latter. An Argand burner is fitted to consume a special quantity of gas of a given quality, just as much as a rifle is specially adapted for a special ball and charge of powder. And the same is true of every kind of gas burner.

The proper regulation of the supply of air to the flame is the chief secret of developing a maximum of light from gas. The greater the quantity, or the richer the quality, of the gas, the more air is required, and hence the better will the flame bear contact with the atmosphere; for, the greater is the quantity of matter to be oxidised, or consumed by combustion. And it is important to observe that the greater the velocity with which gas issues from a burner, the greater is the supply of air to the flame—the more air is the flame brought in contact with. The stream of burning gas from the burner, rising through the (we shall say) quiescent atmosphere of the room, draws in the air upon itself—just as a rapid stream passing through a pool or lake disturbs the stillness of the pool, and draws in upon itself in eddies the surrounding water; and the more rapid the upward stream of gas, the greater the quantity of air thus drawn in upon the flame.

The important bearing which the above statements have upon any question connected with gas illumination is manifest at a glance. They illustrate the chief conditions which affect the illuminating power of gas; they show how great may be the variations of that illuminating power owing to the different kinds of burners used, and also to the manner in which the gas is consumed even in the same burner. The subjoined statistics exemplify both of these points.

The experiments here given were made at intervals during the last two years; and the earlier experiments of the series were made without any reference to the theory or doctrine now in question, but simply in order to ascertain correctly and fairly the capacity of burners to develop the illuminating power or light-giving property of gas. The gas with which the experiments were made was common gas having an average illuminating power of 15 sperm candles, when consumed at the rate of 5ft. per hour in Sugg's London Argand No. 1. This Argand, burning at the above-mentioned rate, was taken as the standard in the experiments, and its light reckoned as 100. The other burners—namely, those experimented with—were made to consume gas at various rates, from 1ft. to 6ft. per hour; and the mode of computing their light with reference to the standard burner was the ordinary and simple one as follows:—Suppose the tested burner gave a light of 40 per cent. (compared with the standard burner) when burning at the rate of 4ft. an hour, then, instead of 40, its light is stated in the fourth column as 50—because the standard burner was consuming 5ft. an hour against the 4ft. consumed by the tested burner. In like manner, if a tested burner gave a light of 60 per cent. (compared to the standard) when burning 6ft. an hour, then, instead of 60, its light is stated in the fourth column as 50—as it was consuming one-sixth more gas than the standard burner. On the other hand, if the tested burner consumed exactly 5ft. an hour, then the figures in the fourth column would be the same as those in the third; for, in this case, both the standard and the tested burner were consuming the same volume of gas.

First, let us give the results of the experiments with fishtail and batswing burners (Table XXXII.).

These experiments show at a glance what a difference the burner makes upon the light emitted by gas. The quality of the gas was, in each experiment, the same; yet how serious the difference in the amount of light given by the several burners—one of them (No. V.) giving at its best barely *one-fifth* of the light obtainable from the gas. But the point specially to be determined is, does the illuminating power of gas vary according to the quantity in which it is burnt, increasing with the rate of consumption? If the doctrine maintained by various experimentalists in this country, and which Mr. Farmer carried to an extreme, were correct, we should find the burners giving more and more light, relative to the quantity of gas consumed, as the rate of consumption is increased; but these experiments show to demonstration that such is not the case. Instead of the gas giving more light as the rate of consumption is increased, it will be seen that, *in every case, there is a point beyond which the light* DECREASES relatively to the proportion of gas consumed. In every case, too, this point lies below, and in most cases is *far below*, the maximum of ordinary gas consumption. Observe the turning points in the case of the different burners. In No. VII. the maximum of light given out is when the gas is burning at the rate of 5ft. an hour—beyond which point the more gas burned the less is the proportion of light which it gives. In No. VIII. the maximum of light is at 4·6ft. an hour; in No. VI. it is at 4·2ft.; in Nos. II. and III. it is about 3ft.; in No. IV. it is at 2ft.; and in Nos. I. and V. at only 1¾ft.!

TABLE XXXII.—*Fishtail Burners.*

Pressure of gas as delivered to burner, in tenths of an inch.	Consumption of gas in feet per hour.	Actual illuminating power—Sugg's London No. 1 at 5ft. being taken as 100.	Illuminating power, calculated to 5ft.—Sugg's London as 100.	Pressure of gas as delivered to burner, in tenths of an inch.	Consumption of gas in feet per hour.	Actual illuminating power—Sugg's London No. 1 at 5ft. being taken as 100.	Illuminating power, calculated to 5ft.—Sugg's London as 100.
		I.				IV.	
·1	1·1	6·8	31·2	·05	1·0	6·9	34·1
·2	**1·7**	**12·2**	**36·0***	**·17**	**2·0**	**18·8**	**47·0***
·4	2·5	17·6	35·3	·26	3·0	27·6	46·1
·6	3·0	20·2	33·7	·61	4·0	30·9	38·6
·8	3·7	22·0	29·8	·95	5·0	31·5	31·5
1·0	4·2	23·0	27·4			V.	
		II.		·3	1·4	4·8	17·4
·1	1·7	19·1	54·8	**·5**	**1·8**	**6·8**	**19·0***
·2	2·6	30·7	59·0	·65	2·0	7·2	18·2
·3	**3·1**	**38·4**	**62·0***	·8	2·4	7·4	15·6
·4	3·6	44·3	61·6			VI.	
·5	4·1	48·7	58·7	·05	1·1	8·0	36·6
·6	4·6	57·5	56·0	·1	1·5	16·6	53·7
·73	5·2	55·9	53·2	·2	2·2	28·1	63·8
				·3	2·8	39·2	68·7
		III.		·4	3·3	46·2	69·0
·35	3·0	29·7	49·6	**·6**	**4·2**	**62·0**	**73·0**
·45	**3·3**	**34·3**	**52·0***	·75	4·7	67·8	72·2
·57	3·8	38·1	50·2	·85	5·1	71·9	70·5
·67	4·2	40·9	48·7	·95	5·4	76·3	70·0
·77	4·6	43·5	47·3	1·0	5·6	77·7	68·7
·87	5·0	45·3	45·3	1·1	5·9	79·5	67·4
			Batswing Burners.				
		VII.				VIII.	
·05	1·3	13·2	53·0	·1	2·0	28·7	70·7
·1	2·2	16·4	74·8	·2	3·4	52·4	77·0
·2	3·6	62·0	85·0	**·3**	**4·6**	**75·6**	**82·2***
·3	**5·0**	**86·5**	**86·4***	·4	5·7	87·2	76·5
·4	6·2	106·0	85·4	—	—	—	—
·5	7·2	111·2	79·4	—	—	—	—
·6	8·1	127·4	78·6	—	—	—	—

*** These lines show the points of consumption at which each of the burners gives the greatest proportion of light from the gas.**

These experiments with batswing and fishtail burners show conclusively that there is no foundation for the above-mentioned doctrine. But when we come to deal with Argand burners, we encounter results which tend to explain how the doctrine arose. As already said, the chief means of obtaining the maximum of illuminating power from gas is to ensure an exactly adequate supply of air to the gas flame; and, with Argands, this point is easily found, for it immediately precedes the stage of combustion at which the flame smokes—*i.e.*, when the air supply becomes deficient, and a portion of the gas is not thoroughly consumed. Indeed, we may state as an absolute rule, that *every burner gives its* OWN *maximum of light* (relative to the quantity of gas consumed) *when its flame is just upon the point of smoking.* With the batswing and fishtail burners used in the preceding experiments, there was no rate of consumption at which the flame of any of them visibly smoked; and this holds good in regard to almost all batswing and fishtail burners when used with common gas, *i.e.*, gas of from 12 to 16 candle-power. But with Argands (owing to the glass chimney which encloses them, and regulates the air supply), it is always possible to increase the consumption of gas to such a point as will make the flame smoke; and hence every burner of this kind can be used in a manner which will give the full illuminating power of the gas, *so far as that is dependent upon an adequate air supply.* Now, as the common fault of Argands is that the gas issues under too great a pressure, *i.e.*, with too great a velocity, thereby bringing the flame in contact with too much air, it follows that the worse the Argand the better will it become when a large quantity of gas is burnt in it; for the air supply, as regulated by the chimney, being nearly a fixed quantity, any excess in the air supply can be neutralised by increasing the quantity of gas consumed. But with all Argands, whether good or bad, the larger the quantity of gas consumed in them (short of smoking), the greater will be the proportion of light which they give from the gas. These facts, we repeat, tend to explain the origin of the erroneous and practically misleading doctrine, that the capacity of gas to give light increases with the quantity of gas consumed.

Here are the results of experiments made with four kinds of the Argand burner—the first (Sugg's London Burner No. 1), one of the best that has ever been constructed; the second and third are ordinarily good Argands; and the fourth, one of the worst Argands that we have met with. The experiments with each burner were carried up to the smoking point, beyond which point experiments are useless, as there is a manifest waste of gas by imperfect combustion (Table XXXIII.).

Here it is shown that the larger the quantity of gas consumed in Argands, short of smoking, the higher the proportion of light which they give from the gas. But it is to be noticed that even at this most favourable point of consumption there is a vast difference in the amount of light given by the different burners (a most important fact, the causes of which will be fully considered in the sequel). In short, then, these experiments with Argands, like the previous ones with batswings and fishtails, show the paramount influence which the burner has upon the amount of light obtained from the gas. For while No. I. gives (what we may for the present call) the full illuminating power of the gas, which is taken as 100, Nos. II. and III. give a light only equal to 78, and No. IV. a light only equal to 34. In other words, the last of these burners, *taken at its best*, gives only one-third of the light which may be obtained from the gas by a really good burner.

TABLE XXXIII.—*Argand Burners.*

Pressure of gas as delivered to burner.	Consumption of gas per hour.	Actual illuminating power—Sugg's London at 5ft. being taken as 100.	Illuminating power, calculated to 5ft.—Sugg's London as 100.	Pressure of gas as delivered to burner.	Consumption of gas per hour.	Actual illuminating power—Sugg's London at 5ft. being taken as 100.	Illuminating power, calculated to 5ft.—Sugg's London as 100.
		I.				III.	
·05 in.	2·1 ft.	5·4	12·7	·2 in.	2·6 ft.	10·3	19·7
·07 ,,	2·8 ,,	19·5	34·2	·3 ,,	3·3 ,,	22·4	33·8
·1 ,,	3·3 ,,	34·1	51·6	·4 ,,	3·9 ,,	36·4	46·7
·14 ,,	4·0 ,,	60·5	75·0	·5 ,,	4·4 ,,	49·2	55·7
·17 ,,	4·4 ,,	77·0	86·1	·6 ,,	4·9 ,,	61·0	65·3
·213 ,,	5·0 ,,	**100·0**	**100·0**	·7 ,,	5·4 ,,	75·6	69·4
				·78 ,,	5·8 ,,	**90·6**	**77·4**
		II.					
·02 ,,	1·6 ,,	2·0	6·2			IV.	
·04 ,,	2·2 ,,	7·7	17·1	·1 ,,	1·8 ,,	1·6	4·5
·07 ,,	2·9 ,,	19·7	33·1	·2 ,,	2·7 ,,	7·8	14·3
·1 ,,	3·5 ,,	32·2	45·4	·3 ,,	3·4 ,,	15·0	21·8
·15 ,,	4·5 ,,	58·9	64·8	·4 ,,	4·2 ,,	21·9	26·0
·2 ,,	5·1 ,,	74·4	72·7	·5 ,,	4·6 ,,	29·3	31·5
·22 ,,	5·6 ,,	**89·1**	**78·8**	·6 ,,	5·2 ,,	**34·7**	**34·3**

The next experiments tend to show, by direct proof, that the illuminating power of gas remains the same, in whatever quantities the gas is consumed, provided that the right kind of burners be employed in the experiments. Every burner is fitted, and every scientifically-constructed burner is expressly devised for a certain rate of consumption, and to use a 6ft. burner with 3ft. of gas is as absurd as to use a 3ft. burner with 6ft. of gas. Hitherto sufficient attention has not been given to this matter (in the experiments of Christison, Farmer, and others, it was wholly overlooked); but, in the construction of his new "London" Argands, Mr. Sugg has acted upon this right principle with great success, although, as will be seen from the next table, there is still room for improvement. The subjoined experiments were made with his series of London Argands, designed to burn respectively 4ft., 5ft., 6ft., and 7½ft. of common gas; and, as before, his No. 1 burner, consuming 5ft. per hour, is taken as the standard = 100. The experiments were carried up to the smoking point of each burner:—

Sugg's London Argands.—[These Argands are so constructed as to check the pressure of the gas "as delivered to the burner;" so that the pressure given in the first column is no indication of that under which the gas is actually consumed, which may be said to be *nil;* whereas, with all the other burners tested in the preceding tables, the pressuré of the gas "as delivered to the burner" is the same as at the point of ignition.]

As with the Argands previously tested, the experiments were carried up to the verge of smoking, at which point the burners give their greatest amount of light:—

TABLE XXXIV.

Pressure of gas as delivered to burner.	Consumption of gas per hour.	Actual illuminating power—No. 1 Argand at 5ft. = 100.	Illuminating power, calculated to 5ft. standard = 100.	Pressure of gas as delivered to burner.	Consumption of gas per hour.	Actual illuminating power—No. 1 Argand at 5ft. = 100.	Illuminating power, calculated to 5ft. standard = 100.
ARGAND No. 0 or C (with 6in. × 1¾in. chimney).				ARGAND No. 2 or F (with 7in. by 2in. chimney).			
·12 in.	2·9 ft.	24·6	42·5	·22 in	4·3 ft.	53·2	61·23
·2 ,,	3·8 ,,	64·6	85·1	·27 ,,	4·9 ,,	74·9	75·75
·24 ,,	4·3 ,,	86·8	99·8	·34 ,,	5·65 ,,	99·0	87·6
·31 ,,	5·0 ,,	108·5	108·5*	·42 ,,	6·65 ,,	118·1	88·8
				·48 ,,	7·2 ,,	133·3	92·6*
ARGAND No. 1 or D (with 6in. × 1¾in. chimney).				ARGAND No. 3 or H (with 7in. × 2in. chimney).			
·16 in.	3·8 ft.	46·2	60·84	·31 in.	5·5 ft.	92·16	83·7
·2 ,,	4·2 ,,	72·25	86·0	·43 ,,	6·7 ,,	123·4	92·0
·25 ,,	5·0 ,,	100·0	100·0	·5 ,,	7·2 ,,	135·2	93·2
·29 ,,	5·5 ,,	118·6	107·6*	·56 ,,	7·8 ,,	154·7	91·1*

* These lines show the points of consumption at which each of the burners gives the greatest proportion of light from the gas.

Although there are some differences here, apparently due to some Nos. of the series being better constructed than the others, these last experiments (especially when taken in connection with all the others), sufficiently indicate that, throughout the common range of consumption there is no difference whatever in the illuminating power of gas; and beyond all question they demonstrate the erroneousness of the doctrine that the light-giving power of gas increases in a higher ratio than the quantity of gas consumed. In fact, the smallest burners here give the best results; so that, in these experiments, the gas gives *less* illuminating power when burnt in large quantity than in small.

There is one point more, connected with the question of illuminating power relative to the quantity of gas consumed, which remains to be noticed. It will be seen that in the case of every one of the burners used in the preceding experiments, there is a point in the rate of consumption *below* which the proportion of light given by the gas falls short of the maximum of light which each of the burners respectively can give.* Indeed, in every case, we have purposely commenced our experiments with each burner at an unduly low (sometimes extremely low) rate of consumption in order that this fact may be exhibited. And, arguing from this fact, the most cautious and moderate upholders of the doctrine that the illuminating power of gas is greatest when the gas is burnt in large quantities, maintain that, whatever be the rate of consumption, a fixed portion of the illuminating power of gas must always be lost, and that, therefore, it is advantageous to burn gas in large quantities. The explanation offered of this alleged fact is, that a *fixed* quantity of gas must be wasted, as regards its illuminating power—must be consumed simply to produce *heat* in sufficient amount to render the remainder of the gas incandescent and light-giving.

As to the amount of this "fixed" quantity of gas which has thus to be wasted, no statement of any kind has ever been offered; and the whole evidence in the matter proves that there is no such fixity of quantity at all, and consequently that the inference drawn from the supposed fixity (viz., as to the light-giving power of gas increasing in a higher ratio than the consumption) is quite unfounded. Indeed, this hypothesis as to the fixity of the quantity of gas (say, a foot or half a foot) which is necessarily wasted, as regards illuminating power, however great or little may be the whole quantity consumed in the burner, is totally opposed to the ordinary laws of Nature. To suppose that, when the rate of consumption is 4ft., as much of the gas must be wasted in order to produce heat enough to render the remainder of the gas luminous, as when the consumption is raised to double that quantity, is preposterous; for obviously there is twice as much gas to be raised to a state of incandescence in the latter case as in the former. In short, it might as well be maintained that the same quantity of coal is required to raise steam, whether the boiler be large or small. Moreover, as shown in the various experiments already given, and as, indeed, is known to every one conversant with such matters, some burners, when consuming exactly the same quantity of gas, vary in the amount of light which they emit to the extent of 30, 50, and even

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* Just as with batswings and fishtails, there is a point of consumption *above*, as well as *below*, which the gas emits less than its maximum of illuminating power. Indeed, this is true of all kinds of burners, Argands included; although with Argands the loss of light, above a certain rate of consumption, is due to smoking (imperfect combustion owing to a deficiency of air), whereas with naked burners it is due to an over supply of air.

70 per cent., showing a corresponding loss or waste of the illuminating power, and thereby proving that the waste is anything but a fixed quantity.

In truth, in this case, as with all the variations in the proportion of light obtained from gas, it is simply a question of burners. No burners have as yet been devised for the consumption of gas in very small quantities, nor are they much needed. But, lacking such burners, let us make use of a rude apparatus for diminishing the air supply—viz., a metal disc placed above the upper end of the chimney of an Argand —and observe the result. The burner to which it was applied was Sugg's London Argand No. 0, *the very best burner yet constructed,** and which gives its maximum of light when burning at the rate of 5ft. per hour—the gas being of fifteen candle-power. The following Table XXXV. shows the extraordinary change made by the apparatus upon the light of this burner when consuming gas in small quantities:—

TABLE XXXV.

Pressure of the gas as delivered to the burner.	Consumption of gas per hour.	Illuminating power *without disc.*	Illuminating power *with disc.*
		Calculated to 5ft. per hour. Compared with Sugg's London No. 1, burning 5ft. an hour, as 100.	
·064 in.	1·65 ft.	7·36	63·5
·075 ,,	2·05 ,,	15·2	90·1
·1 ,,	2·4 ,,	30·7	93·3
·2 ,,	3·9 ,,	88·3	101·0
·25 ,,	4·5 ,,	103·9	Smokes.
·27 ,,	5·0 ,,	109·6	Smokes.

Here is seen that in the initial experiment the application of the disc instantaneously increased the light from the gas *nine-fold!* And in the second experiment the application even of this rude apparatus sufficed to develop from only *two* feet of gas an amount of light proportionately greater than is obtainable from ordinarily good Argands (or any other kind of burner) when burning at the usually higher rates of gas consumption. So that the loss of light when gas is burned in small quantities, so far from being a fixed and constant quantity, is shown to be simply owing to the burner—not to any variation in the light-giving power of the gas, but to the mechanical apparatus employed for developing that power. Just as (as best shown in batswings and fishtails) a similar and equally great loss of light takes place when the consumption of gas is raised *above* a certain point, which varies with each burner.

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* It is necessary to state that, notwithstanding the great care and skill with which Mr. Sugg constructs his burners, he has not yet succeeded in making them entirely uniform, so that some of these burners, although nominally alike, give appreciably different degrees of illuminating power. [Note by Ed.—Great improvements have been made since this report was written, and the observation does not apply at the present time.]

Let us now summarise the results of the preceding experiments —

I. In the case of the batswing and fishtail burners, there is a point of consumption *above* which every increase in the rate of consumption produces a *decrease* of light relative to the quantity of gas consumed.

II. The point of consumption at which each of those burners gives its maximum of light, relative to the quantity of gas consumed, varies enormously; two burners (Nos. I. and V., page 194) giving most light from the gas when the rate of consumption is only 1¾ *feet per hour.*

III. With Argands, on the other hand, the light from the gas steadily increases in a higher ratio than the consumption. In other words, the larger quantity of gas consumed in Argands (up to the smoking point), the greater the amount of light obtained relatively to the quantity of gas consumed.

IV. Alike with Argands, batswings, and fishtails, whatever be the rate of consumption at which the maximum of light is obtained (in other words, taking each of the burners at its best), there is nevertheless a striking difference in the degree of light obtained from the same quantity of gas—some burners giving a light equal only to 20, while others give a light equal to 60, 80, and 100.

V. The best kinds of Argands (Sugg's London burners) give a nearly equal amount of light, relatively to the quantities of gas consumed; the experiments with them tending to show that, within the ordinary range of consumption, the illuminating power of gas remains the same.

VI. Finally, even as regards very low rates of consumption (rates, indeed, at which gas is never burnt for illuminating purposes), the application merely of a rude apparatus for regulating the air supply suffices to make only *two* feet of gas give a light equal in proportion to the greatest amount of light obtainable from the gas when consumed at any higher rate in a really good burner.

The establishment of the true facts of the case, simple and natural as they are, not only serves to remove a stumbling-block and perplexity from the path of science, but, as will be evident in the sequel, is of importance in the practical question as to what is the best mode of consuming gas, with a view to obtain efficiently and economically its highest amount of illuminating power.

UNGOVERNED FLAT-FLAME BURNERS.

Bray's Gas Burners are so well known as to hardly require description, but it will nevertheless be as well to indicate the special features of the various kinds.

(1) *Specials* are in three forms, like most other burners

of this maker, viz., "Union Jet," "Slit Union," and "Batswing," to suit various pressures and qualities of gas.

"*Special*" *Burners* (Figs. 64, 65, 66).—For general purposes the union jet is claimed to be the most serviceable burner on the market. The "Special" burners are made in the union jet, batswing and slit union types, to suit any pressure or quality of gas, by means of a check, so placed that it cannot be tampered with or disarranged. They give a large, well-shaped flame, are indestructible, not liable to get out of order, and show, after years of steady use, the same standard conditions under test. Sizes: union jets, 00000 to 8; batswing, 000 to 9; slit unions, 1 to 9.

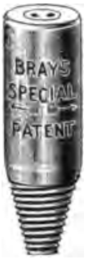


Fig. 64.

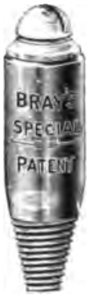


Fig. 65.

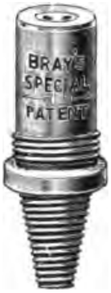


Fig. 66.

(2) "*Adjustable Special*" *Burners* (Figs. 67, 68) are only intended for use where the pressure of gas is too high for the ordinary burner, as is the case in the upper part of elevated districts, and the top floors of tall office buildings and factories. They are modifications of the "Specials," but differ from them in that they should be fitted by experienced persons, while the "Specials" can be put on by anyone. The "Adjustable Special" consists of two burners screwed together. The bottom burner limits the supply of gas to the top, and after deciding the size of the top burner, the pressure and consumption of gas is at once determined and regulated by the use of the proper size bottom burner. The

top burners are made in union jets (sizes 1 to 8), batswing and slit union (sizes 1 to 9), and the bottom burners in union jets (sizes 00 to 6). The illuminating power is about the same as that of the "Specials." The tops and bottoms of the "Adjustable Special" burners of course vary in size. The tops range from 1 to 9; the bottoms from 00 to 6; and are all interchangeable.

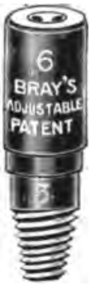


Fig. 67.

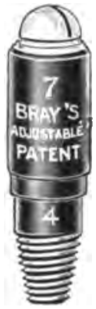


Fig. 68.

(3) "*Regulator*" *Burners* (Figs. 69, 70, and 71).—Though their illuminating power is not equal to that of the "Special" or "Adjustable Special" burners, or so much under control, these "Regulators," as they are usually called, are nevertheless claimed to be much superior to the ordinary steatite tip for general purposes. A steady, well-shaped flame is produced by the combination of the "tip" and the arrangement in the interior of the burner. For "Clusters" or "Beacon Lights," or for purposes where two or more burners are required for

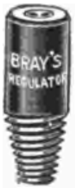


Fig. 69.

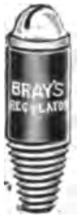


Fig. 70.

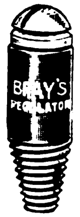


Fig. 71.

converging lights, the "Regulator" is recommended. Sizes: union jets, 00 to 7; slit unions, 1 to 8; batswing, 000 to 8.

(4) The *Gas Economiser* (Figs. 72 and 73) is an economical adaptation of the "Adjustable" burner, but is less generally useful. For some purposes, however, the "Gas Economisers" are found to be acceptable, and their cheapness is then in their favour. The top part only is required, and is made merely to slip on to the ordinary "Regulator" burners. The "Gas Economisers" are made in union jets, batswings, and slit Unions. Sizes: union jets, Nos. 5 and 7; batswings, Nos. 5 and 7; slit unions, Nos. 5 and 7, the slit union type being recommended.

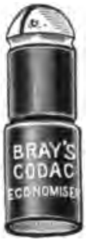


Fig. 72

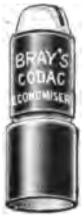


Fig. 73.

(5) "*Non-Regulator*" *Burners.* — These burners are similar in outward appearance to the "Regulators," but shorter in the socket, and are without the interior regulating medium. They do not prevent roaring and flickering, but they are useful burners for many purposes. Sizes of "Non-Regulator" burners: union jets, 0 to 8; batswings, 00 to 9; slit unions, 2 to 9.

(6) "*Ratstail*" *or One-hole Burner.*—This burner shoots out a straight jet, like a rat's tail, and is used to some extent for lighting purposes, heating, cooking, pipe-lighting, &c. The sizes usually made are Nos. 00 to 6 included, but larger sizes can, of course, be made.

(7) "*Sunlight*" *Burners.*—These are union jet burners, adapted for use in sunlights, with very strong cases, tips

extra secured, and special regulating medium. Sizes: union jets, 00 to 7.

(8) "*Oven*" *Burners* are specially made for use in gas ovens. Sizes: Union jets, Nos. 00 and 0.

(9) "*Acetylene*" *Burners* (Figs. 74, 75, and 76).—Great skill and care is required in the manufacture of acetylene burners; the drilling and fitting demand the utmost precision of workmanship. Bray's acetylene burners are undoubtedly of very high grade, and are made in union jet sizes, 000, 0000, and 00000; patent Ceetee union jets, ½ft. and ¾ft.; "Ratstail" or one-hole burner, sizes 00000000 to 000. Bray's Luta burner (Fig. 76) is constructed on the Bunsen principle.

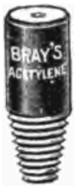


Fig. 74.

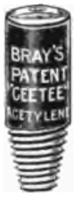
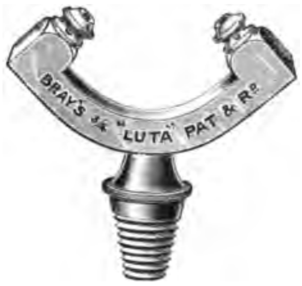


Fig. 75.



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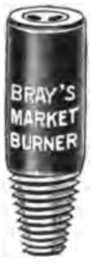

Fig. 77.

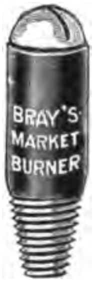

Fig. 78.

(10) "*Market*" *Burners* (Figs. 77 and 78).—These are made in union jets, batswing, and slit union burners of a

large size, suitable for markets or places where large flames are required, and for outside lighting. The sizes are: Union jets, Nos. 8 and 9; batswing, Nos. 10 and 11; slit union Nos. 10 and 11.

(11) "*Railway Carriage*" *Burners.*—These burners are specially made for use in the lighting of railway carriages. Sizes: union jets, 0000, 000, 00.

(12) "*Standard*" *Burners.*—Lighting power, 20, 30, 40, 50, 60, 70, and 80 candles each. These burners were introduced in February, 1879, to compete, for street lighting with the electric light and the Argand system of gas lighting. Messrs. Bray and Co. state that before their introduction there were no slit union burners which yielded more than 14·8 candles per 5 cubic feet of 16-candle gas, whilst these "Standard" burners give a light of 17 candles per 5 cubic feet of 16-candle gas—an increase of over 14 per cent.—and maintain this high lighting power through consumptions of 8ft. to 25ft. per hour. The pressure at the point of ignition should not be less than six-tenths, and may be increased to ten-tenths without diminishing the yield of light per foot of gas consumed. The "Standard" burners are suitable for lighting large areas, either singly or in clusters, and with or without lanterns.

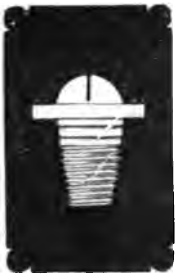

Fig. 79.

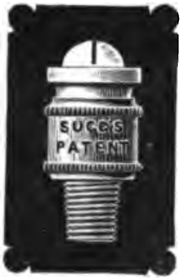

Fig. 80.

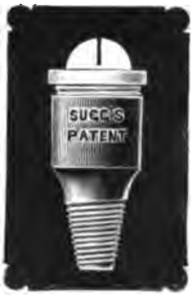

Fig. 81.

Messrs. Sugg and Co.'s Table-top Steatite Flat-flame Burners are shown in Figs. 79 to 83, and their *Hollow-top Steatite Burners* in Fig. 84.

Single Flat Flame Burners with Governors.—With the object of preventing the passage of an excessive quantity of gas through the burner, the governed burner, as it is called, was introduced. There are numerous patterns of these, but they are all on the same principle, viz., the restriction of the gas supply by the action of a plug or needle rising or falling in the gas-way, the movement being regulated by the pressure of the gas upon a diaphragm, which may be made of leather, steatite, brass, &c., their object being to ensure the burner consuming the particular rate of gas for which it is best adapted. Their effect on the duty of the gas is most marked in the case of burners consuming less than 4·3 cubic feet of gas per hour, as, by reason of the steadying and better oxidisation of the flame, nearly double the amount of light is afforded. The reason of this is that a good burner employed with a governor restricts the flow of gas to a suitable rate, whereas, if the same burner was employed without a governor or other restricting arrangement, it would allow too large a volume of gas to pass, to prevent which it has to be made of such a size that it cannot burn the gas under the most favourable conditions.

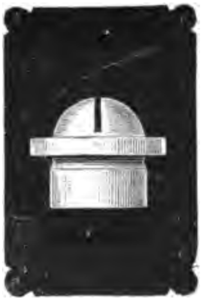
Fig 82.

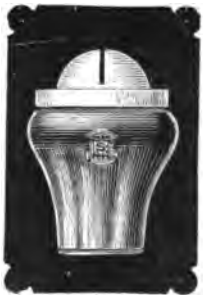
Fig. 83.

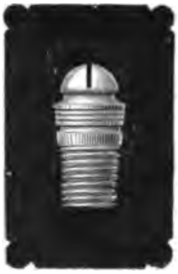
Fig. 84.

The Peebles Needle Governor Burner, manufactured by Messrs. D. Bruce Peebles and Co., of Edinburgh, is specially designed for use in all kinds of situations either of position or altitude. As its name implies, every burner contains a governor to control the flow of gas to the burner tip, so as to ensure a constant rate of consumption under varying conditions of pressure of the gas in the supply pipe. The burner tip is designed to give such a pressure at the actual point of ignition as will ensure the best illuminating power of the gas used being obtained. In other words, to obtain the best results from two burners, one burning 5 cubic feet per hour, and the other 2 cubic feet per hour, different burner tips must be used, so that the rate at which the gas issues from the burner may be such as to secure the best illuminating effect. This result cannot be readily obtained by the use of larger governors on the main supply pipe, because when gas is used for other purposes—*i.e.*, heating and cooking—it is not convenient to reduce the pressure in the service pipes so low as is necessary to obtain good lighting results with ungoverned burners.

For dwelling-houses or other buildings where there is usually a difference of altitude of many feet from the basement to the top rooms, and where different sizes of burners would be required, automatic governor burners are best, as the varying pressure at the different altitudes is thereby corrected at the point required, viz., the burner tip, and the light from the smaller flames approximates more nearly to the ratio afforded by the larger flames in proportion to the volume of gas burnt.

As will be seen from the illustrations (Figs. 85 to 89), the Peebles needle burners are scientifically constructed instruments, being simple in their mechanism and therefore not liable to get out of order. Referring to the section shown in Fig. 87, the cone shown resting on the needle automatically rises and falls according to the pressure of the gas; and, being balanced between the outlet and inlet gas pressures, closes or opens the aperture at the top of the inner case, thereby silently regulating the quantity of gas passing at all times.

It is claimed for these burners that they maintain a uniform consumption of gas under all pressures from four-tenths up to thirty-five tenths of an inch; and, consequently, that the gas is consumed at the pressure most suitable for each particular burner tip.

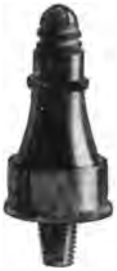
Fig. 85.

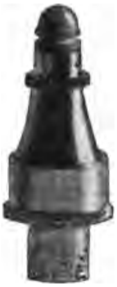
Fig. 86.

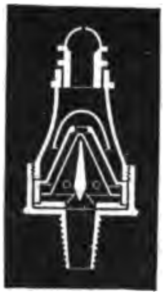
Fig. 87.

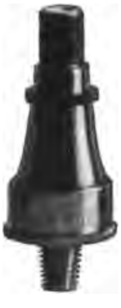
Fig. 88.

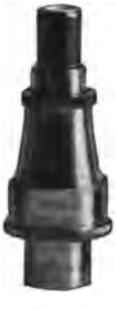
Fig. 89.

Messrs. Sugg's Flat-flame Governor Burner, fitted with steatite float, in strong brass case, and table-top burner, is shown in Fig. 90. The latest form of Sugg's patent steatite-float governor burner is the "cone-top" (Fig. 91), suitable for warehouse, workshop, or private dwelling, for consumptions of 3 to 6 cubic feet per hour. Fig. 92 shows the "Westminster," with brass arms for carrying a globe.

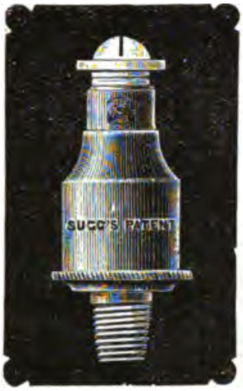

Fig. 90.

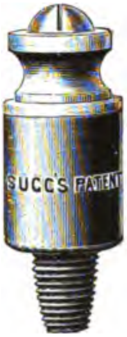

Fig. 91.

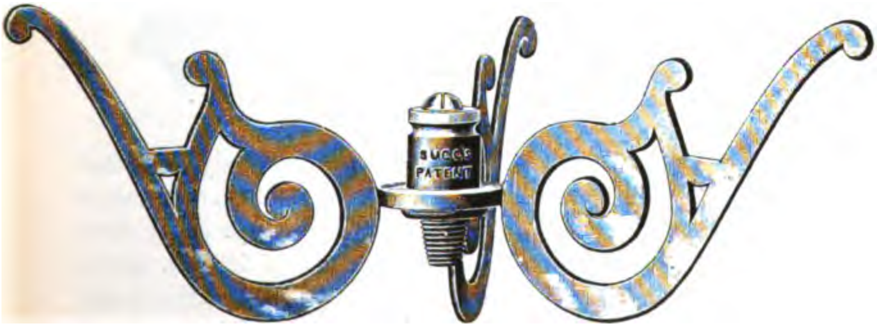

Fig. 92.

Flat-flame Burners in Lanterns.—As the object of these combinations of burners and lanterns is to throw the light downwards and outwards, they must be tested not only in the horizontal direction, but at different angles between the horizontal and the vertical below. It will, of course, be understood that the "duty" expresses not merely the direct light emitted from the burners, but also that thrown in the same direction by the aid of the reflectors in the lantern. In the case of several lamps the author has examined, such as the "Newington" and "Lambeth" lamps, a duty of 5·4 candles was obtained. These lanterns, however, do not emit rays at a higher angle than about 5 deg. above the horizontal, whereas other lamps, such as the "Camberwell" and "Balham," emit rays of light at 26 deg. and 27 deg. above the horizontal, but with a correspondingly decreased "duty." This constitutes an essential difference in regard to their use for street lighting, the former type being more adapted to affording a brighter illumination in open spaces where a specially good light is required, whilst the latter are more suitable for general street lighting of the ordinary type.

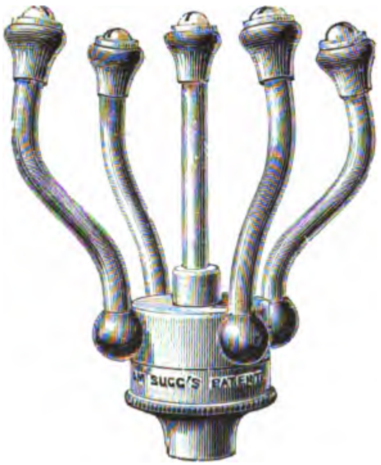

Fig. 93.

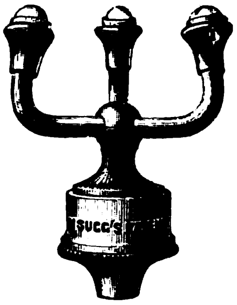

Fig. 94.

Grouped Flat-flame Burners without Lanterns.—Messrs. Sugg and Co.'s five-flame combination burner is shown in Fig. 93, and the same firm's "Billingsgate" combination burner in Fig. 94. These are groups of flat-flame burners, having from two burners to five or more as required. By the heat radiated from such large masses of flame the principle of "regeneration" is, to a slight extent, brought into play, with the result that a duty of 3·8 candles per foot may be readily obtained in the horizontal direction without the aid of reflectors. The advantage of this form of burner is that it avoids the constant attention required by the Argand or other more complicated make of burner, and therefore costs less for attendance.

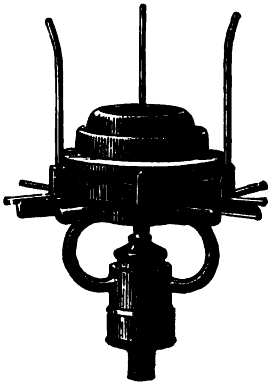

Fig. 95.

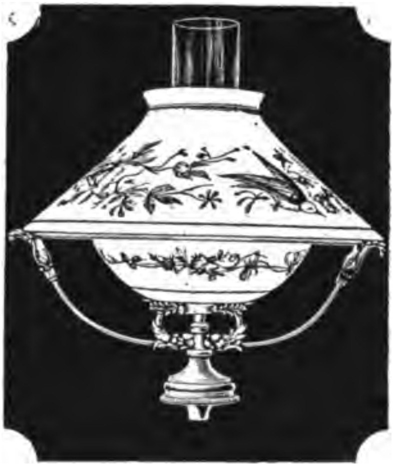

Fig. 96

Sugg's Improved "London Argand Burner with Steatite Float Governor.

For general use in workshops, &c., grouped flat-flame burners, fitted with a simple form of reflector, are perhaps as economical in first cost and upkeep as can be desired.

Argand Burners (Figs. 95 and 96).—Where the necessary attention can be given in order to keep the chimneys clean, this form of burner has still many advocates. The greatly improved forms now give comparatively very high duties, ranging from 3·0 to 4·2 candles per cubic foot of gas consumed.

Various proposals have been made from time to time to improve the light of the burner by fixing a central plate over the steatite for the purpose of deflecting the flame, so as to give it the form of a cup; one such burner examined was found to give a duty of 4·4 candles per foot. Unfortunately this high duty is speedily diminished by a deposit or "bloom" on the sides of the glass chimney, and thus the initial advantage is soon lost, and if the glass is not very frequently cleaned a very poor result is obtained. This deposit on the chimneys is the one drawback to all forms of burners involving their use.

Numerous attempts have been made to increase the efficiency of Argand gas burners by forming them of two or more concentric rings of burners, so as to yield a series of Argand flames within one another. In this manner the late Sir James Douglas employed no less than six rings of flame; the gas supply to each being independent of the rest. The following are the average results of the tests ma·le by the author and Professor William Foster with these:—

Burner.	Consumption of gas, cubic feet per hour.	Illuminating power.	Duty.
Douglas's six-ringed Argand	91·4 ...	436·3 ...	4·71
Douglas's three-ringed Argand ...	21·6 ...	85·1 ...	3·93
Sugg and Co.'s four-ringed Argand	94·8 ...	451·3 ...	4·77
Sugg and Co.'s two-ringed Argand	28·5 ...	120·8 ...	4·25

"*Regenerative*" *Burners.*—Although it is largely due to Mr. Frederick Siemens that we owe the introduction of the great improvements in gas burners by the system of heating both the air and gas supply on their passage to the point of ignition, yet we are indebted to Faraday for the experimental demonstrations of the economical results arising from the heating of the air supply by the "waste heat" of the burner. An Argand burner, fitted with a double chimney as proposed by Faraday, was exhibited at the Crystal Palace Exhibition by Messrs. Henry Greene and Son, and was tested by the author in conjunction with

Professor Foster, with the result that it was found to give a mean duty of 3·63 candles per cubic foot of gas, the absolute consumption being remarkably low—3·78 cubic feet of gas per hour.

The original burners constructed on Mr. Siemens' principle were a great advance upon anything previously known, giving duties of 4½ to 5·2 candles per foot without the aid of reflectors. The improvement made by Mr. Grimston gave still higher results, viz., 8·6 candles per cubic foot of gas consumed, when the light was tested in the most favourable position, viz., with the burner directly overhead, and assisted by a suitable reflector. A smaller burner, constructed by Mr. F. C. Clark, gave 6·9 candles per cubic foot under the most favourable circumstances.

Improvements were effected from time to time by Wenham, Sugg, and others, until Mr. Sugg produced a burner which gave about 11·0 candles per cubic foot of gas, without the aid of reflectors. This seemed to be the climax in the way of intensity obtainable by direct combustion of ordinary 16-candle coal gas. Unfortunately, the initial expense, and the attention required by this type of burner, seems to have too heavily handicapped it in the race against the modern developments of the incandescent mantle type.

Tests of Burners.—The following are observations by Mr. Fairley, of Leeds, on a series of experiments on various burners with gas having an illuminating power of 17·5 candles when tested by the 15-hole Argand burner, equal to about 19-candle gas when used in the London Argand 24-hole burner:—

The burners tested are of four kinds, each with modifications by different makers. The "union jet" or "fish tail;" the "batswing;" the "slit union" or "flat flame;" and the "Argand." These are each made with or without a check at the bottom of the burner to diminish the pressure, or with or without a small governor attached to each burner to keep the consumption constant.

The Siemens regenerative burner is somewhat different from any of these, but is a modified Argand with fittings for heating the gas and

Table XXXVI.—BRAY'S BURNERS—UNION JETS.

Bray's Medium Lighting Power Regulator Union Jets.

Number of burner.	Pressure in inches.	Cu. ft. per hour.	Illuminating power in standard candles.	Illuminating power per 5 cu. ft.
0	·5	2·5	2·97	5·94
0	1·0	3·6	3·8	5·27
0	1·5	4·1	4·2	5·12
1	·5	2·6	3·95	7·6
1	1·0	3·9	4·72	6·05
1	1·5	4·95	5·22	5·27
2	·5	3·3	5·8	8·8
2	1·0	4·9	7·2	7·35
2	1·5	6·02	7·2	5·95
3	·5	3·5	6·8	9·7
3	1·0	4·8	6·9	7·2
3	1·5	6·2	7·5	6·05
4	·5	4·65	12·2	13·1
4	1·0	6·67	14·2	10·6
4	1·5	8·16	14·2	8·8
5	·5	5·72	17	14·9
5	1·0	7·97	20	12·6
5	1·5	9·73	21·8	11·2
6	·5	5·9	18	15·2
6	1·0	8·35	23	13·8
6	1·5	10·6	28	13·2
7	·5	6	19	15·8
7	1·0	8·65	25	14·4
7	1·5	10·9	25	11·5*
8	·5	7·05	26·2	18·6
8	1·0	10·6	36·4	17·2
8	1·5	12·4	33·0	13·3*

Bray's Medium Lighting Power "Special" Union Jets.

Number of burner.	Pressure in inches.	Cu. ft. per hour.	Illuminating power in standard candles	Illuminating power per 5 cu. ft.
0	·5	2·16	5·1	11·8
0	1·0	3·05	6·2	10·2
0	1·5	3·82	7·0	9·2
1	·5	2·8	7·0	12·5
1	1·0	4·02	8·3	10·3
1	1·5	4·8	9·2	9·6
2	·5	3·04	9·5	15·6
2	1·0	3·97	12·2	15·4
2	1·5	5·1	15·2	14·9
3	·5	3·43	11·3	16·4
3	1·0	4·9	15·6	15·8
3	1·5	6·03	17·6	14·6
4	·5	3·73	13·3	17·8
4	1·0	5·15	17·4	16·9
4	1·5	6·57	22·4	17·1
5	·5	4·8	17·6	18·3
5	1·0	6·67	24·4	18·3
5	1·5	8·3	30	18·2
6	·5	5·48	20·1	18·3
6	1·0	7·65	28·4	18·6
6	1·5	9·2	34·2	18·7
7	·5	6·47	23·4	18·1
7	1·0	8·05	30·2	18·8
7	1·5	11·1	35·4	18·9
8	·5	7·55	27·6	18·4
8	1·0	10·6	39·3	18·9
8	1·5	13·2	46·4	17·6
9	·5	7·84	30·2	19·3
9	1·0	11·2	43·4	19·4
9	1·5	13·8	49·8	18

BRAY'S SLIT UNIONS.

Bray's Medium Lighting Power Slit Unions.

Number of burner.	Pressure in inches.	Cu. ft. per hour.	Illuminating power in standard candles.	Illuminating power per 5 cu. ft.
1	·5	3·04	9·4	15·4
1	1·0	4·8	14	14·6
1	1·5	6·13	16·4	13·4
2	·5	3·33	11	16·5
2	1·0	5·2	16·1	15·4
2	1·5	6·47	19·4	14·9
3	·5	4·22	13·8	16·4
3	1·0	6·37	20·2	15·9
3	1·5	8·14	25·8	15·9
4	·5	4·25	14·8	17·4
4	1·0	5·88	20·6	17·5
4	1·5	7·95	26·5	16·6
5	·5	5·25	19·0	18·2
5	1·0	8·14	28·4	17·45
5	1·5	10·2	36·4	17·8
6	·5	5·67	22·2	19·6
6	1·0	8·6	33·6	19·4
6	1·5	11·1	39·5	17·8
7	·5	5·88	23·4	19·9
7	1·0	9·04	37·2	20·6
7	1·5	12·1	44	18·2
8	·5	6·18	22	17·9
8	1·0	9·4	36·2	19·3
8	1·5	11·9	46	19·4
9	·5	6·7	28·8	21·5
9	1·0	10·5	40·4	19·2
9*	1·5	13·2	46·4	17·6

Bray's Medium Lighting Power "Special" Slit Unions.

Number of burner.	Pressure in inches.	Cu. ft. per hour.	Illuminating power in standard candles	Illuminating power per 5 cu. ft.
1	·5	2·06	6·4	15·5
1	1·0	3·53	10·2	14·6
1	1·5	4·41	12·4	14·1
2	·5	2·75	9·5	17·2
2	1·0	4·22	14·4	17
2	1·5	5·49	17·6	16·1
3	·5	3·04	10·8	17·8
3	1·0	4·61	16·4	17·6
3	1·5	5·88	19·9	16·9
4	·5	3·82	14·2	18·6
4	1·0	5·69	20·8	18·3
4	1·5	7·35	25·6	17·5
5	·5	4·12	15·4	18·7
5	1·0	6·37	23·4	18·4
5	1·5	7·94	28·5	18·0
6	·5	5·0	19·6	19·6
6	1·0	7·55	29	19·2
6	1·5	9·7	37	19·1
7	·5	6·08	23·5	19·5
7	1·0	8·6	33·4	19·4
7	1·5	10·7	41	19·2
8	·5	6·9	26·8	19·5
8	1·0	10·0	41·8	20·9
8†	1·5	11·2	42·2	18·8
9	·5	8·4	34	20·25
9	1·0	12·6	45·6	18·1
9†	1·5	13·0	40	15·4

* Roars. † Roars slightly.

TABLE XXXVII.—BRAY'S BATSWINGS.

	Number of burner.	Pressure, in inches.	Cubic feet per hour.	Illuminating power in standard candles.	Illuminating power per 5 cu. ft.		Number of burner.	Pressure, in inches.	Cubic feet per hour.	Illuminating power in standard candles.	Illuminating power per 5 cu. ft.
BRAY'S MEDIUM LIGHTING POWER BATSWINGS.	1	·5	2·68	6·6	12·3	BRAY'S MEDIUM LIGHTING POWER "SPECIAL" BATSWINGS.	1	·5	2·68	8·2	15·4
	1	1·0	4·26	10	11·7		1	1·0	3·86	13·2	17
	1	1·5	5·35	11·2	10·4		1	1·5	5·15	15·4	14·9
	2	·5	3·17	9·4	14·8		2	·5	2·97	10	16·8
	2	1·0	4·95	13·2	13·4		2	1·0	4·46	15·8	17·7
	2	1·5	6·14	14·0	11·4		2	1·5	5·65	19·6	17·4
	3	·5	4·16	12·6	15·1		3	·5	3·37	12·4	18·4
	3	1·0	5·64	16·6	14·8		3	1·0	5·25	20·4	19·4
	3	1·5	7·83	21	13·4		3	1·5	7·13	24	16·8
	4	·5	4·26	14	16·4		4	·5	3·67	13	17·7
	4	1·0	6·74	21·2	15·6		4	1·0	5·55	20·6	18·6
	4	1·5	7·81	24	15·3		4	1·5	7·13	26	18·2
	5	·5	4·76	15·4	16·2		5	·5	3·86	14·6	18·9
	5	1·0	6·93	20·4	14·7		5	1·0	5·85	22·6	19·4
	5	1·5	8·72	25·8	14·7		5	1·5	7·53	28	18·6
	6	·5	6·04	20	16·5		6	·5	4·86	19·4	20
	6	1·0	8·82	29·4	16·6		6	1·0	7·53	31·6	21
	6	1·5	11·1	31·6	14·2		6	1·5	9·6	39	20·4
	7	·5	6·9	26·6	19·3		7	·5	5·75	23·2	20·2
	7	1·0	10·0	39·8	19·9		7	1·0	8·72	38	21·7
	*7	1·5	13·5	45	16·6		7	1·5	11·3	50	22
	8	·5	6·1	22	18		8	·5	6·36	26	20·4
	8	1·0	9·3	32·4	17·4		8	1·0	9·3	42	22·6
	8	1·5	11·6	40	17·3		8	1·5	12·1	53	21·8
	9	·5	6·5	24·8	19·1		9	·5	6·93	27	19·5
	9	1·0	10·1	38	18·9		9	1·0	9·31	40·4	21·7
	*9	1·5	13·1	40	15·2		9	1·5	11·6	51	22

BRONNER'S, UNGAR'S, SUGG'S CHECK BURNERS; SILBER'S ARGANDS.

BRÜNNER'S BURNERS.	4 A top	·5	2·45	9·2	18·6†
		1·0	2·9	10·7	18·5
		1·5	3·7	12·6	17·0
	5 A top	·5	4·1	15·3	18·7
		1·0	5·8	19·5	16·8
		1·5	7·2	20·4	14·2
	4 B top	·5	2·87	8·8	15·2†
		1·0	3·66	12·4	16·8
		1·5	4·76	16·8	17·5
	5 B top	·5	5·25	18	17·2
		1·0	6·9	27	19·6
		1·5	8·95	32·4	18·1
UNGAR'S ECONOMISERS.	3	·5	3·26	10·8	16·5
	3	1·0	4·48	14·6	16·35
	3	1·5	5·46	19	17·38
	3½	·5	2·65	7·6	14·8
	3½	1·0	4·05	12·15	14·9
	3½	1·5	4·9	14·8	15·08
	5	·5	4·25	13·4	15·8
	5	1·0	5·54	20	18·1
	5	1·5	6·82	24·5	17·9

SILBER'S ARGANDS.		H. C.			
	Air burner.	7¾	4·8	17	17·7
		9¾	5·43	20·8	19·2
		10¼	5·8	22	19·0
	Tubulated burner.	7¾	4·8	18·6	19·4
		9¾	6·69	24·4	18·4
		10¼	6·88	26·4	19·3
SUGG'S "WINSOR" CHECK BURNERS.	3	·5	1·2	4·2	17·4
	3	1·0	2·6	8	15·4
	3	1·5	3·6	11	15·3
	4	·5	4·0	15	18·8
	4	1·0	6·5	24	18·5
	4	1·5	8·6	30	17·4
	5	·5	4·2	15·4	18·3
	5	1·0	6·8	26·2	19·2
	5	1·5	9·1	33·6	18·5
	6	·5	4·95	19·2	19·3
	6	1·0	7·33	28	19·1
	6	1·5	9·3	32·8	17·6‡
	7	·5	5·2	19·4	18·6
	7	1·0	7·6	29	19·1
	7	1·5	9·6	34	17·6‡
	8	·5	5·5	21·2	19·2
	8	1·0	8·0	30·5	19·1‡
	8	1·5	—	—	—
	9	·5	5·8	21·4	18·2
	9	1·0	8·8	34	19·4
	9	1·5	11·1	40	18·0‡

* Roars. † Smokes. ‡ Flares and smokes. H. C., Height of chimney in inches.

TABLE XXXVIII.

BRAY'S LARGE BURNERS, SIEMENS' REGENERATIVE BURNERS, &c.

	Number of burner.	Pressure in inches.	Cu. ft. per hour.	Illuminating power in standard candles	Illuminating power per 5 cu. ft.
SUGG'S "CITY" SCREW REGULATORS.	4	·5	2·87	9·0	15·6
	4	1·0	4·5	16·4	18·2
	4	1·5	5·9	22·5	19·2
	5	·5	3·4	12·4	18·3
	5	1·0	5·25	19·0	18·1
	5	1·5	6·84	24·6	18
	6	·5	4·05	14·4	17·8
	6	1·0	6·4	24·0	18·8
	6	1·5	8·23	29·8	18·2
	7	·5	5·15	18·0	17·4
	7	1·0	7·43	28·0	18·9
	7	1·5	9·2	31·6	17·5*
	8	·5	5·92	20·8	17·6
	8	1·0	8·8	32·0	18·3
	8	1·5	11·4	41·2	18·1*
HARROGATE BURNERS.	5	·5	4·9	17·2	17·6
	5	1·0	7·1	24·4	17·2
	5	1·5	8·5	28·2	16·6
	6	·5	5·6	20·5	18·3
	6	1·0	8·0	29·6	18·6s
	6	1·5	9·7	32·2	16·6*
	7	·5	5·1	18·6	18·2
	7	1·0	6·9	25·6	18·7
	7	1·5	8·7	32·2	18·5

	Number of burner.	Pressure in inches.	Cu. ft. per hour.	Illuminating power in standard candles.	Illuminating power per 5 cu. ft.
BRAY'S LARGE BURNERS.‡	C'dle				
	30	·5	8·45	28·4	22·7
	30	1·0	13·5	58·4	21·5
	40	·5	8·5	38·4	22·7
	40	1·0	13·3	58·6	22
	50	·5	9	41·2	22·8
	50	1·0	14	61	21·8†
	60	·5	9	42	23·3
	60	1·0	14	61·4	21·9†
	70	·5	8·8	40·3	22·9
	70	1·0	13·1	61·4	23·4†
SIEMENS' REGENERATIVE BURNERS.	Flat flame		6·6	52·4	39·7
			7·4	55·8	37·7
	No. 1 circular burner.		20	128	32
	No. 2 circular burner.		38	205	27

The increased power of these burners is chiefly due to the heating of the air and gas by waste heat from the flame, and in a less degree to the reflection of light by the porcelain next the flame

SILBER'S AND OTHER DUPLEX BURNERS.

	Number of burner.	Pressure in inches.	Cu. ft. per hour.	Illuminating power in standard candles	Illuminating power per 5 cu. ft.
SILBER'S.	B	·5	3·46	10·4	15s
	B	1·0	5·6	21·6	19·2
	B	1·5	7·2	26·4	18·4
	C	·5	4·55	15·6	17·1s
	C	1·0	7	27	19·4
	C	1·5	9	34	19
	D	·5	6·4	23·9	18·7s
	D	1·0	9	36	20
	D	1·5	11·3	43·5	19·3
	E	·5	6·42	24	18·6s
	E	1·0	10	40·5	20·2
	E	1·5	13·1	50·5	19·3
	B§	·5	3·36	11·2	16·6
	B§	1·0	5	20·3	20·3
	B§	1·5	6·5	26	20·1
	B‖	·5	2·07	4·7	11·4
	B‖	1·0	2·95	6·8	11·6
	B‖	1·5	4·03	7·6	9·5
WEBSTER'S.	4	·5	3·45	12	17·4
	4	1·0	5·14	20	19·5
	4	1·5	6·6	21·2	16
	5	·5	3·88	14	18
	5	1·0	5·8	22·4	19·3
	5	1·5	7·65	18·8	12·4fl
	6	·5	4·45	18·4	20·6
	6	1·0	6·75	26	19·3
	6	1·5	8·4	21·2	12·6fl

	Number of burner.	Pressure in inches.	Cu. ft. per hour.	Illuminating power in standard candles.	Illuminating power per 5 cu. ft.
BARNICOLA'S.	2	·5	2·92	10·3	17·6
	2	1·0	4·85	16·4	17·0
	2	1·5	6·4	19	14·8
	3	·5	4·9	18·8	19·2s
	3	1·0	7·2	25·8	18
	3	1·5	8·8	29	16·4
	4	·5	5·9	23	19·6s
	4	1·0	8·3	32·5	19·6
	4	1·5	10·48	28·2	13·2
	6	·5	5·9	22·5	19s
	6	1·0	8·8	33	18·7
	6	1·5	10·85	37·4	17·2fl
GIBSON'S.	1	·5	6·5	21·2	16·3
	1	1·0	7·8	28	18
	1	1·5	9·3	32·3	17·3
	2	·5	6·15	20·4	16·5
	2	1·0	7·8	28	18
	2	1·5	9·3	32	17·2
HERON'S.	3	·5	2·75	7·8	14·1
	3	1·0	4·45	14·8	16·6
	3	1·5	5·95	18·4	15·5

* Flares and smokes.

† The supply at command could not give 1·5in. pressure with these burners.

‡ For street lighting.

§ With tap on double.

‖ With tap off single.

S—Smokes. fl—Flares.

air by the waste heat of the flame. This principle was first applied, many years ago, by Leslie, and by Faraday, and gives an increase of from 30 to 60 per cent. in the light obtained.

As a rule, burners with governors are preferable to burners without them, even where a governor is attached to the meter. Any burner with too little gas is flickering and unsteady, and often smoky, and with too much gas it is also wasteful and generally smoky. Each burner has a particular pressure at which it gives its best results.

TABLE XXXIX.

SUGG'S AND PEEBLES' GOVERNOR BURNERS (BURNERS WITH GOVERNORS). BEHL'S AND BORRADAILE'S GOVERNORS.

	Number of burner.	Pressure in inches.	Cu. ft per hour.	Illuminating power in standard candles	Illuminating power per 5 cu. ft.		Number of burner.	Pressure in inches.	Cu ft. per hour.	Illuminating power in standard candles.	Illuminating power per 5 cu. ft.
SUGG'S LONDON ARGANDS.	30	·5	5·2	20	19·2	PEEBLES' PATENT GOVERNOR.	3	·5	2·8	9·5	16·9
	bole						3	1·0	3·4	11·0	16·2
	30	1·0	5·4	20·8	19·3		3	1·5	3·4	11·0	16·2
	30	1·5	5·4	20·8	19·8		4	·5	3·5	12·6	18
	33	·5	5·7	21·5	19		4	1·0	4·2	14·9	17·8
	bole						4	1·5	4·2	14·9	17·8
	33	1·0	5·9	21·8	18·5		5	·5	3·97	15·2	19·1
	33	1·5	6	21·8	18·4		5	1·0	5	19	19
							5	1·5	5	19	19
							6	·5	4·85	19	19·5
							6	1·0	6·2	24·8	20
							6	1·5	6·2	24·8	20
SUGG'S CHRISTIANIA †	4	·5	3	10·8	18		7	·5	6·05	22·9	19
	4	1·0	4·7	16·8	18		7	1·0	8·1	31·2	19·4
	4	1·5	4·7	16·8	18		7	1·5	8·1	31·2	19·4
	5	·5	4	14·6	18·2		8	·5	6·24	24	19·2
	5	1·0	6·1	22·4	18·4		8	1·0	8	32	20
	5	1·5	7·1	26	18·4		8	1·5	8	32	20
	6	5·	4·1	14·8	18·1						
	6	1·0	6·4	24	18·8						
	6	1·5	7·0	28	20	BEHL'S PATENT GOVERNOR BURNER.		·5	3·06	8·9	14·5
								1·0	3·85	11·1	14·4
								1·5	3·85	11·1	14·4
						BORRADAILE'S PATENT GOVERNOR.	Ft.				
SUGG'S CHRISTIANIA.*	4	·5	2·65	10·0	18·8		2	·5	2	6·6	16·4
	4	1·0	4·4	16·0	18·2		2	1·0	2·1	6·9	16·4
	4	1·5	4·4	16·0	18·2		2	1·5	2·1	6·9	16·4
	5	·5	4·2	16·2	19·2		5	·5	4·9	18·5	19
	5	1·0	5·75	22·5	19·6		5	1·0	5	19	19
	5	1·5	5·75	22·5	19·6		5	1·5	5	19	19
	6	·5	5	19·6	19·6		10‡	·5	7·3	28	19·3
	6	1·0	6·6	25·5	19·3		10‡	1·0	9·8	39	20
	6	1·5	6·6	25·5	19·3		10‡	1·5	9·8	39	20

* Large for globes. † Small. ‡ Sent out without burner, fitted with Bray's 30-candle burner to be tested.

The burners most sensitive to variations of pressure are the union jets and the Argands. These are much improved by a check or governor attached to the burner. Where a very steady uniform localised light is desired, and a burner not very sensitive to the effects of dust, the union jet may be employed, but it gives less light for the gas consumed than the other burners, especially with the smaller sizes.

The slit burners are more sensitive to dust, but the proportion of light obtained per foot of gas equals or surpasses in some instances that obtained from the Argands.

The Argands require more care and attention than any other form. Unless reflectors are used, the light is given off chiefly in the horizontal plane of the flame, so that it is much darker above or below the burner. The chimney glasses require daily cleaning.

An Argand is more smoky than any other burner if too much gas is supplied to it, and gives exceedingly little light when the supply is too small.

Some makers send out duplex burners (two small burners mounted so that the flames coalesce). These burners are smoky at low pressures, giving a flame of the same character as that from a large-sized ordinary burner with too small a supply of gas. At higher pressures, 1·5in. and upwards, they give better results, but not superior or often so good as those obtained from the best single burners.

None of the batswing burners are suitable for globes, while the union jets and slit unions or flat flames are suitable. No globes should have an opening, at the bottom, of less than 3in., otherwise a great part of the light is lost. Mica or porcelain tops placed over the globes help to increase the light, and to diminish the production of smoke.

Albo-Carbon System.—From time to time various methods have been suggested and tried for enriching the gas, either at or immediately before the burner. None of these methods seem to have had much success until the Albo-Carbon Company introduced their process of enriching the coal gas by means of naphthalene stored in a solid condition in a vessel so situated that it is heated by the gas flame, the naphthalene thus volatilised being carried forward by the gas to the burner. The system had a great advantage in that it gave an exceedingly bright and agreeable light. The naphthalene used is a bye-product of the gas manufacture, being, indeed, the substance which all gas engineers endeavour to retain in the gas to the greatest extent possible, but which immediately begins to crystallise out of the gas in cold weather, and forms deposits, thus not only depreciating the value of the illuminating power of the gas, but choking the supply pipes. This substance has the chemical composition $C_{10} H_8$, melts at 174·2° Fah., and boils at 420° Fah. The effect of its use for increasing the light afforded by ordinary coal gas will be seen by the following table :—

TABLE XL.

Consumption of gas per hour in cubic feet.	Consumption of naphthalene per hour in grains.	Average illuminating power in candles during the experiment.	Illuminating power of gas if burnt alone, and giving a duty of 2·8 candles per cubic ft.	Illuminating power in candles given by the naphthalene.	Quantity of naphthalene in grains required to give a duty of 1 candle per hour.	Time occupied in the experiments. Minutes.	Pressure of gas.
3·6	221·6	27·2	10·1	17·1	12·9	90	1·5
3·2	123·5	19·1	9·0	10·1	12·2	60	1·1
3·4	119·0	20·0	9·5	10·5	11·3	30	1·1
3·6	180·0	23·2	10·0	13·2	13·7	60	1·5
3·4	213·0	27·5	9·6	17·9	11·9	60	1·5

The mean of the figures in the sixth column shows a "duty" of the naphthalene equal to 12·4 grains per candle per hour. Special experiments showed that although the apparatus soon began to afford a good light after being lit, yet an interval of fifty minutes elapsed before the effect of the naphthalene was at its maximum.

CHAPTER XII.

INCANDESCENT GAS LIGHTING.

THE title of this chapter is used to denote those burners which are employed for heating solid substances to a high temperature (incandescence) by means of a mixture of combustible gas and air, the mixture being in such proportions that the gas itself does not directly contribute to the lighting effects obtained.*

The immediate forerunners of the now widely-known Welsbach system were the burners of M. Clamond and of Mr. Lewis. Each of these gentlemen arrived at similar results by slightly different methods, since the apparatus of each was essentially a blow-pipe, with an air supply maintained by special mechanical arrangements.

The Clamond burner was inverted, the gas and air passing downwards through a box-like arrangement made of metal. From the lower surface was suspended a conical basket, the walls of which were composed of twisted threads of calcined magnesia (magnesium oxide). A cage, composed of a few thin platinum wires, supported the basket. Its size was 2¼in. long, the section of the cone at the base being ⅞in. in diameter.

The baskets were made from a mixture of the hydrate and acetate of magnesia, brought into a condition of paste or cream by means of water. After they were made from this material on a suitable mould, they were dried and fired. The acetate and hydrate losing certain of their constituents, became converted to a condition of oxide. They were necessarily extremely fragile. The air supply was artificially maintained at a pressure of about 6in. of water.

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* See Report on Crystal Palace Exhibition, 1882–3, by W. J. Dibdin and Professor William Foster.

The Lewis burner was in the form of a rectangular cylinder made of fine platinum wire, fixed on the extremity of an open pipe. The mixture of gas and air was burnt within this platinum cylinder, causing the incandescence of the metal. The air supply to the burner was under a pressure of 14in. of water. Advantage was taken of this high pressure, and consequent great velocity of the air issuing from the nozzle of the burner, whereby a further supply of air was drawn " by induction " from the external air through the lateral open pipes.

The details of the various tests, and the quantity of gas and air used in each case, are shown in the following table :—

Rays from Burner, Horizontal.

	Clamond (average).	Lewis (average).
Air used in cubic feet	**41·6**	**48·1**
Gas used in cubic feet	**7·7**	**13·4**
Illuminating power	**32·7**	**62·7**
Duty per cubic foot of gas	**4·26**	**4·68**

Welsbach's System.—While the above systems indicated the direction of the path of progress, they yet failed to realise the full advantage now known to be attainable, and it was reserved for Dr. Auer von Welsbach to introduce the system now so well known by his name.

The first public exhibition of Dr. von Welsbach's system of incandescent gas light was made in London in February, 1887. At that time there were many fears expressed as to the possibility of the new system being successfully placed on the market on a commercial basis and for a short time the company had a hard struggle to overcome the difficulties which are always met with by those who introduce original work.

These, however, were soon surmounted, and the public are indebted to their untiring exertions for the benefits conferred by such an enormous stride in artificial illumination by means of gas.

The historical character of this new departure warrants rather more detailed description than has been given in the present chapter to the various methods of obtaining light from gas.

The essential feature is the "Mantle," which is woven of Sea Island and Egyptian cotton, well washed to remove earthy matter and grease. The mantle is at first a network of cylindrical shape, almost twice the size of the finished article. It is then immersed in a solution of the nitrates of thorium and cerium in the proportion of 99 per cent. of thorium oxide and 1 per cent. of cerium oxide, which gives to it its luminous value, the solution containing about 14 per cent. of these salts. The excess of solution is then removed from the cotton by passing the latter through small wringing rollers, the pressure of which is so regulated as to leave a definite determined quantity of the solution in the fibres. The mantle is now dried on a mould in a hot-air chamber. When dry the mantles are stretched out to uniform shape by hand, and then carried to the fixing-room, where the top of the impregnated mantle is fixed with a solution containing another group of rare earths, viz., lanthanum, zirconium, and traces of magnesia, the object being to ensure the shrinkage of that end of the mantle on the asbestos thread with which it is subsequently sewn, to form the thickened and supporting end of the mantle. When dried, the mantle is sewn and trimmed, and then handed to the "burners," whose duty it is to first shape the mantle on a wooden mould, and then to burn off the cotton by means of a Bunsen burner flame, thus leaving a skeleton of the cotton thread composed of the oxides of thorium and cerium. This "skeleton" is then heated from the top downwards over a high-pressure Bunsen burner for three minutes, during which process it gradually shrinks to almost half its original size, and is caused to take the required shape. The mantle is now finished and ready for use; but, as it is too brittle for transit, it has to be stiffened. This is done by dipping it into a solution of collodion and camphor, after which it is dried by hot air, and thence passed to the packers and trimmers.

The extent to which this industry has developed may be indicated by the fact that at the Palmer Street Works of the Welsbach Company over 40,000 mantles are manufactured daily, no less than 600 girls being employed.

In an interesting account of the Welsbach system read by the chemist of the company, Mr. W. Mackean, F.C.S., before the Society of Chemical Industry, in 1891, it is shown (Table XLI.) that by altering the nature and composition of the fluid employed for impregnating the mantles, the light obtained can be varied from an intense white light to a golden yellow or greenish colour, which differ to a certain extent in their diffusive power, the following mixtures giving the lights referred to:—

TABLE XLI.—*White Light.*

I.

	Per cent.
Zirconium oxide	40
Lanthanum „	40
Thorium „	20

II.

Zirconium oxide	40
Lanthanum „	60

III.

Yttrium oxide	20
Thorium „	80

These may be considerably altered without affecting the colour of the light.

TABLE XLII.—*Yellow Light.*

I.

	Per cent.
Lanthanum oxide	40
Thorium „	28
Zirconium „	30
Cerium „	2

II.

	Per cent
Zirconium oxide	47
Lanthanum ,,	50
Cerium ,,	3

Orange Light.

I.

Lanthanum oxide	40
Thorium ,,	30
Zirconium ,,	27
Didymium ,,	3

II.

Lanthanum oxide	50
Thorium ,,	40
Niobium ,,	10

Green Light.

Thorium oxide	50
Lanthanum ,,	20
Erbium ,,	30

According to Mr. MacKean, any other oxides may be employed in the compositions, but the presence of some, such as alumina and magnesia, are very detrimental to the duration of the illuminating power.

The mantle is used by suspending it over a Bunsen burner in which the air and gas are mixed before arriving at the point of ignition, so that there is a complete absence of the ordinary white flame, in place of which the metallic oxides of which the mantle is composed become heated to incandescence, and yield the brilliant light now so well known.

At the time of the introduction of the Welsbach system in 1887, the company obtained a duty from ordinary 16-candle gas of about 10 candles. Their 1893 burner increased this to about 17 candles, whilst the latest form—the 1898 pattern—is claimed to yield a duty of no less than 27 candles of light per cubic foot of gas consumed, and this even with such a low consumption, in the case of their smallest-sized burner, of no more than ¾ cubic foot per hour. This is truly a marvellous development, and when considered in relation to the best results obtainable at the time of the Crystal Palace Exhibition of 1882-83 shows the wonderful advance which has been made since then, an advance which promises to be paralleled in the case of the incandescent electric light; as, by the application of the same principles, viz., the incandescence of these rare metals and metallic oxides, there is every reason to anticipate some early pronouncement of an equally startling character.

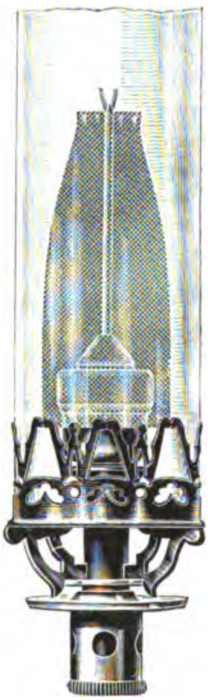


Fig. 97.

Welsbach C Burner (Fig. 97).—The introduction of the improved Welsbach mantle in 1893, and this burner, placed gas in a position unapproachable by its competitors as a cheap illuminant for both indoor and outdoor lighting. This burner is now so well known that any detailed description of it would be superfluous but it might be mentioned that the essential parts of the burner consist of the gallery or upper part, which carries the mantle, rod, and chimney; the Bunsen tube; and the nipple with five holes for the gas inlet. Some millions of these burners are now in use, and until the introduction of the Kern burner, described below, this was undoubtedly the most economical and effective means of public lighting. The burner gives an average of 60 candles with a gas consumption of 3½ cubic feet per hour. In 1897 close on 2000 of these burners were already installed in the streets of Liverpool for public lighting, and now the number has been increased to over 10,000, and Liverpool can truly claim to be one of the best lighted cities in Europe. Cluster lamps of four burners are used at important junctions, and in the main streets double burners. In Liverpool, electricity is supplied by the Corporation's own works at 2d. per unit for public lighting; but notwithstanding this low charge, it is still found that the streets can be lighted more effectively and economically by the use of Welsbach burners and gas at 2s. 6d. per 1000. Mr. C. R. Bellamy, Lighting Engineer to the Corporation, has given the following table of comparison of costs, taking the Liverpool charges for gas and electricity, and assuming lamps to be 50 yards apart:—

	Per mile.		
	£	s.	d.
By electricity	546	8	9
By double Welsbach burners...	127	0	0
By single Welsbach burners	89	10	0

Ramsgate, Ipswich, and Winchester are other towns which were early in availing themselves of the advantages of the Welsbach system for public lighting.

Welsbach Kern Burner (Fig. 98).—The introduction of the Welsbach Kern burner in 1898 greatly strengthened the position of the Welsbach Company and the gas companies throughout the country in their public lighting. As compared with the C burner, the Kern has the following advantages:—

(1) A lighting efficiency of 25 to 30 candles per cubic foot of gas, compared with 16 to 18 candles from the C burner.

(2) The burner can be supplied in a variety of sizes, but in whatever size a lighting efficiency of 25 to 30 candles per foot of gas remains constant.

(3) The consumption of more gas results in more light, and not a diminution beyond a certain point, as is the case with the C burner.

(4) No chimney being necessary, a fruitful source of destruction of mantles is obviated.

The Kern burner is the invention of Ottmar Kern, and is patented in this country under No. 294, 1897, &c. The specification states that the object of the invention is "to produce a burner that shall raise the refractory mantle or hood to a higher degree of incandescence than has hitherto been accomplished with the same amount of illuminating gas, and at the ordinary pressures at which gas is usually supplied, and this without the use of any artificial draught, such as is ordinarily produced by glass chimneys and sometimes by mechanical blowers." This high incandescence is obtained "by constructing a burner in which the admission of air to the gas is so adjusted that, in the mixture obtained, the amounts of oxygen and hydrocarbon gas are, practically, in the proportion of the chemical equivalents of these two gases; thereby the mixture becomes self-burning—that is to say, it will burn in a closed chamber from which the external air is excluded. This self-burning mixture is, by my improved burner, caused to issue from the burner tip under greater pressure than with an ordinary Bunsen burner (of the gas-distributing system), and with greater speed than that with which the flame can propagate itself through the mixture; whereby the flame is prevented from burning backwards, and is thus steadily maintained above the exit opening of the burner tip. Within the flame of such self-burning mixture there is a zone of superior incandescence, which zone I call the hyper-incandescent zone, which is very much hotter than the rest of the flame. My burner is so arranged that the refractory filament, or mantle of fila-

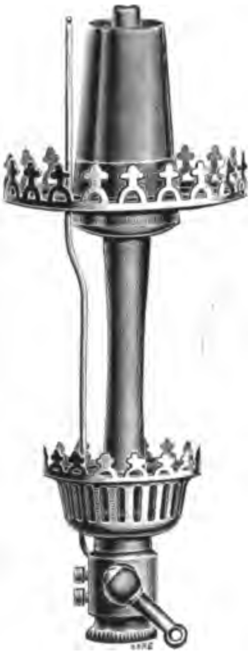


Fig. 98.

ments, is exceedingly close to, or immersed in, this hyper-incandescent zone, whereby the filament, or mantle of filaments, also becomes hyper-incandescent, and thus furnishes, with the same consumption of gas, a more intense, light, or the same amount of light with a less consumption of gas." This ideal mixture is obtained by constructing a burner on the following lines:—The Bunsen tube is composed of two cones, the lower cone being the shorter of the two (in the Kern burner as manufactured now the tube is a hyperbolic spindle), and this arrangement increases the quantity of air forced through the pipe, and produces "a more thorough mixture of air and gas, and at the same time delivers the mixture at a much higher pressure than the ordinary Bunsen burner does." The inventor calls the lower cone "the mixing cone," and the upper cone "the suction cone." The head of the burner is conical, and also consists of an inner perforated cone which supports at the

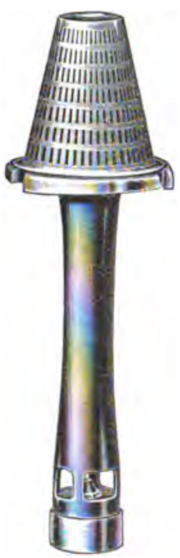


Fig. 99.

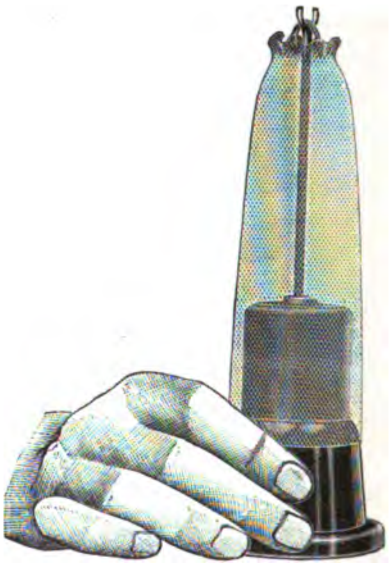


Fig. 100.

Method of removing Top for Cleaning and Inspection.

top a toothed disc, the teeth of which partially close the space between the two cones, and thus take the place of the wire gauze in an ordinary Bunsen type burner. The inner cone assists in mixing the gas and air, and also in heating the mixture to a certain temperature before arriving at the point of ignition.

The three sizes of Kern burners most used for public lighting are those known as the Nos. 2, 3, and 4, which, with a gas consumption of 2¼, 3, and 4 cubic feet, give 50, 75, and 100 candle-power respectively. In South London alone between fifteen and twenty thousand of these burners have been fixed in the streets during the last year or two with most satisfactory results. Owing to the economy in gas which is able to be effected by the use of this burner, Mr. George Livesey, of the South Metropolitan Gas Company, has been able to offer free of cost new lamps for old to the districts which his company supplies.

The alleged trouble with mantles has sometimes been a point brought against the use of the Welsbach system for public lighting. It is no doubt true that care must be used with mantles, but this has always been impressed upon lighting authorities; and for the best results to be obtained, it is essential that there should be an intelligent understanding of the principle of the system in making an

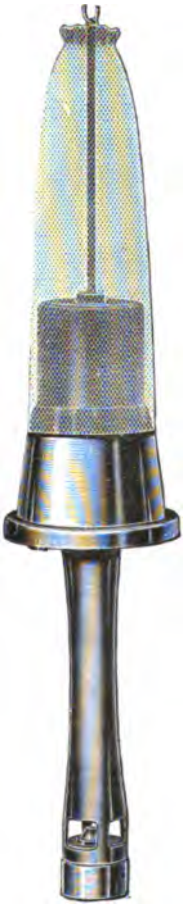


Fig. 101.
Burner Complete.

installation, and that a suitable lantern should be employed.

Welsbach Kern High-pressure Burner.—Figs. 99 to 104 show the Kern burner in its modified form for high-pressure lighting. A special point about this burner is the easy way in which the top can be removed, without in any way disturbing the mantle, for the purposes of inspection and cleaning. The outer cone, instead of being screwed on, is fixed by means of a three-clamp fastening, as shown in the illustration of the separate parts of the burner. This method of fitting has the advantage that, by a single turn of the hand, the upper part of the burner, with mantle and rod complete, can be lifted away from the Bunsen tube. The burner works at from 8in. to 10in. water-pressure, and gives from 30 to 35 candles per cubic foot of gas, so that with a consumption of about 10 cubic feet per hour 350 candle-power is obtained. The fact that these burners can be used either singly or in clusters, is a very strong point in their favour for public lighting, compared with an electric arc lamp, for by this means a much more even distribution of light can be obtained than from a

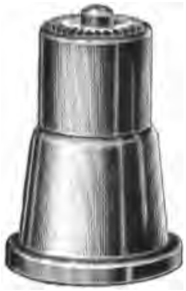


Fig. 102 —Outside Cone.

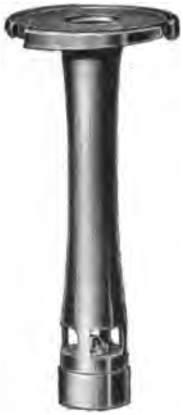


Fig. 103.—Bunsen Tube.

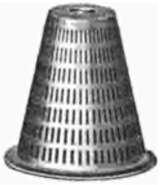


Fig. 104.—Inner Cone.

single point, as is the case when electricity is used. These burners were used in lighting the grounds of the Glasgow International Exhibition.

The Welsbach Self-intensifying Burner (Fig. 105).—This, the latest burner brought out by the Welsbach Company, is the invention of Messrs. Brett and Henneberger, the Company's engineers, and marks an important advance in high-power incandescent gas lighting, which should prove of the greatest assistance to gas companies in competing with electricity. It has an efficiency of between 30 to 40 per cent. in advance of the best results hitherto obtained at low pressure. The burner is designed to burn about 10 cubic feet of gas per hour at ordinary pressure, and to give a light of 300 candles. This result has been obtained by some slight, yet important, modifications of the Kern burner, and by the addition of a metal chimney, which enables the right quantity of air to be drawn in to effect complete combustion. A glass cylinder about 4½in. long is suspended at the lower end of the metal chimney by means of a simple bayonet joint, and surrounds and protects the mantle. In the case of the self-intensifying burner, because it works from ordinary main pressure—say, from 15-10ths to 30-10ths—neither compressing plant nor high-pressure mains are necessary, and consequently no pulling up of the roads is involved in its installation.

As might be expected, the success of the Welsbach system has brought many rivals into the field, the most prominent of which is the Sunlight Incandescent Company, whose first mantles gave a light of a so-called "golden" colour. These two companies have now amalgamated, the Sunlight Company being under licence by the Welsbach Company. The "Sunlight Incandescent Mantle Company" has recently introduced a modification in the manufacture of the mantles with good results.

One of the most important developments of the Welsbach system is the use of the gas at a high pressure, when the

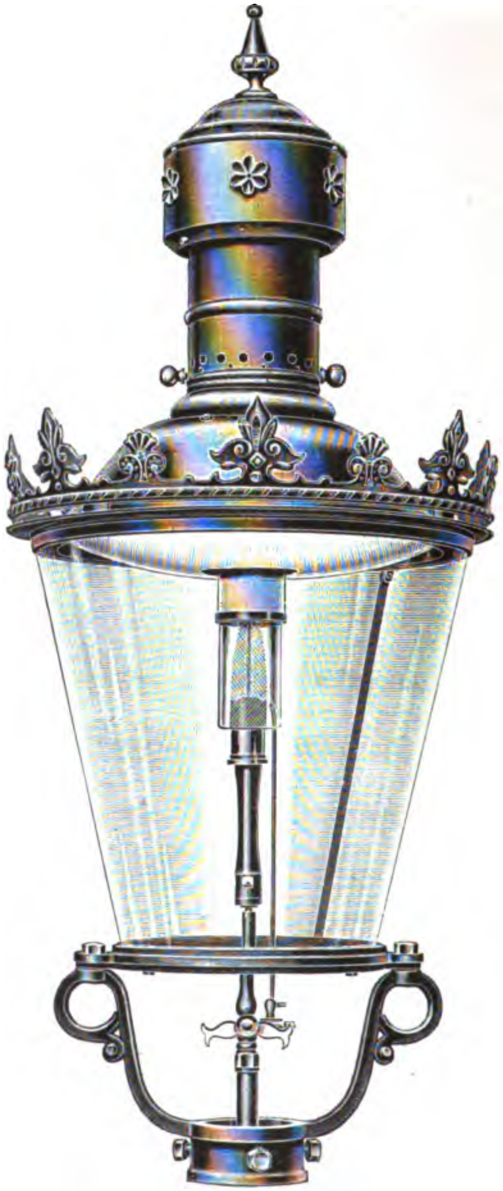


Fig 105.

intensity of the light yielded by the mantle is largely increased. This fact has been utilised by the Intensified Gas Light Company, Limited, who, under the Somzée-Greyson patents, are introducing their high-pressure system of intensified gas lighting, a system which has been worked out by Mr. Leon Somzée and Mr. Greyson de Schodt, of Belgium.

Practically the appliances for producing high-power gas light, according to the Somzée-Greyson system, consist of three essential parts, viz.:—The burner, the mantle, and the gas compressor.

The burner is composed of a gas injector, a mixing chamber, and a burner top and mantle holder combined, which are so arranged that, automatically, the exact proportion of air is drawn in, and intimately mixed with the gas flowing out of the injector, so that at some distance from the top of the burner a flame of very high temperature is obtained, which, by a wire gauze that never gets red-hot, is absolutely prevented from firing back.

As the quantity of air drawn in is always proportionate to the amount of gas supplied by the injector, the heat, and therefore the light, is proportionate to the varying consumption.

The mantle (Fig. 106), which is manufactured specially for the Intensified Gas Light Company by the Welsbach Incandescent Company, gives an intensely brilliant light, and is used without a chimney. This allows the burners to be arranged in groups, and at the same time does away with an important cause of loss of light and breakage of mantles.

The gas compressor is a small apparatus for increasing the pressure of the gas. It is placed on the house side of the meter at the entrance end of the service pipe, and is of very small power and dimensions. It may be driven by water from the water supply pipe, or by any other small mechanical power available. The pressure of gas is raised to a maximum of 9in. water gauge, so that the existing gas

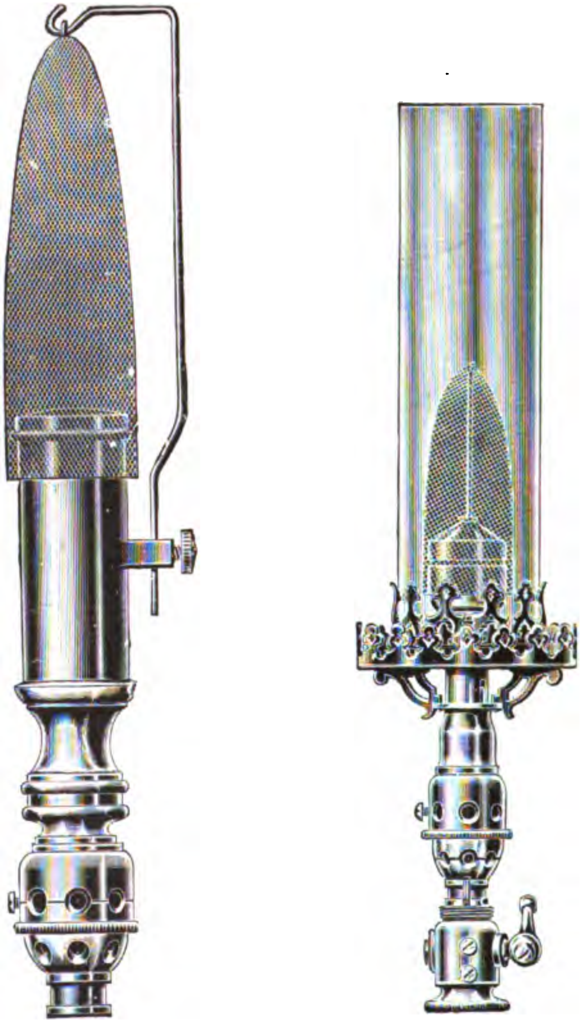


Fig. 106.—The Intensified Gaslight Co.'s Incandescent Mantles.

service pipes and fittings can be used. The motive power required for working the apparatus is insignificant, and the cost, if driven by the ordinary water service, only amounts, the company claim, to at the utmost one penny per 1000 cubic feet of gas consumed.

Table XLIII., issued by the patentees, gives a comparison of the illuminating power and cost of the intensified system, with electric, incandescent, and arc lamps, fishtail gas burner, Argand burner, regenerative burner, and Welsbach incandescent "C" burner, taking gas at 3s. per 1000 cubic feet:—

TABLE XLIII.

Description of light.	Illuminating power, standard candles.	Consumption per hour in cubic feet.	Mantles.	Cost per 1000 candles per hour in pence.
Electric incandescent light	15	0·25d. per hour.	—	15·2
Electric arc lamps at 6d. per unit	—	—	—	3·0
Fishtail burner	15	5	—	12·5 to 22·5
Argand burner	25	8·8	—	
Regenerative burner ...	430	81·	—	3·1
Welsbach incandescent "C" burner	50	3·5	0·8	3·3
Intensified	275	10·	0·2	1·5

To make the foregoing comparison still clearer, the makers append the following table, showing the consumption for a year of 16 candle-power gas, giving a light of 4000 candles by the intensified system, as compared with the ordinary fishtail and Welsbach "C" burners:—

No. of burners.	System.	Consumption in 1000's of cubic feet.	Cost, taking gas at 3s. per 1000 cubic feet. £	s.	d.
267	Fishtail	2436 ...	365	8	0
80	Welsbach "C" ... burner	511 ...	76	13	0
14½	Intensified ...	265 ...	39	15	0

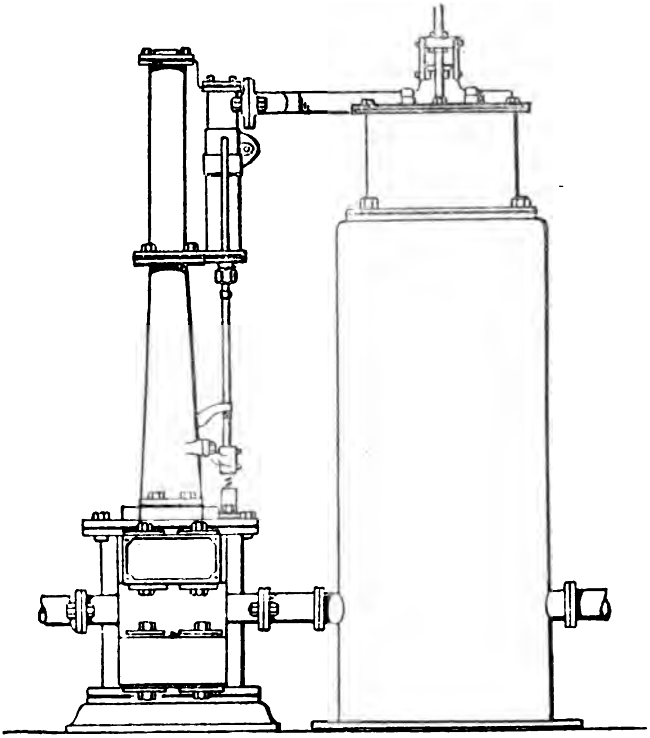


Fig. 107.—Water Pressure Increaser—Elevation

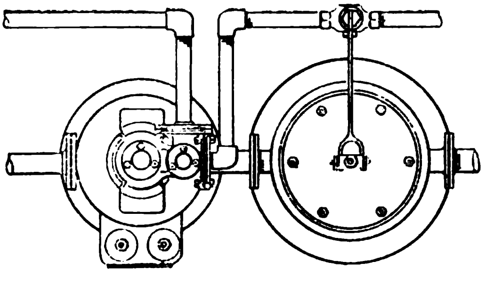


Fig. 108.—Water Pressure Increaser—Plan.

Messrs. Sugg and Co.'s System of High and Low-pressure Incandescent Lighting by Gas.—(1) This system depends on the raising of the pressure of gas as it is supplied in the street mains from about 2in. to 10in. at the foot of the governor of the burner in the street or other lamps. The pressure increaser worked by water power, as will be seen by Figs. 107 and 108, consists of a hydraulic ram actuating the piston of a gas pump, which alternately sucks in and expels the gas under a pressure of 12in. The gas under this pressure passes into a cylinder of a capacity considerably greater than the capacity of the pump. This cylinder neutralises the shock of the ram when the stroke changes from the up stroke to the down stroke and *vice versâ*. On the top of this cylinder is fixed a governor consisting of a strong leathern gasholder, which has a stroke of about 3in., and actuates a lever, which opens or closes the valve through which the supply of water to the ram flows, and reduces the flow of the water when it exceeds 10in. or 12in., the pressure at which the gas may be required to be raised, according to circumstances. The gasholder of the governor is lifted by the pressure of the gas in the cylinder, which passes through a small opening between the cylinder of the gasholder to the governor, so as not to cause any sudden raising or falling of the holder. By this means nearly a constant pressure is maintained, and from the outlet of the cylinder the gas passes to a governor sufficient to supply the number of lights the apparatus is made for, and maintain the pressure constantly without variation, no matter whether there are only one or two lights on, or the full number.

(2) *Sugg's Steam-pressure Increaser* is worked by steam at a pressure of from 15 lb. to 20 lb., according to the number of lights on the apparatus. The number of lights worked by an apparatus 3ft. 9in. long, 3ft. 3in. high, and 2ft. deep, is 300, each consuming 10ft. of gas per hour, and giving a light of more than 300 candles, so that the entire volume of light it is capable of giving at full speed is 90,000 candles. Of course, smaller sizes can

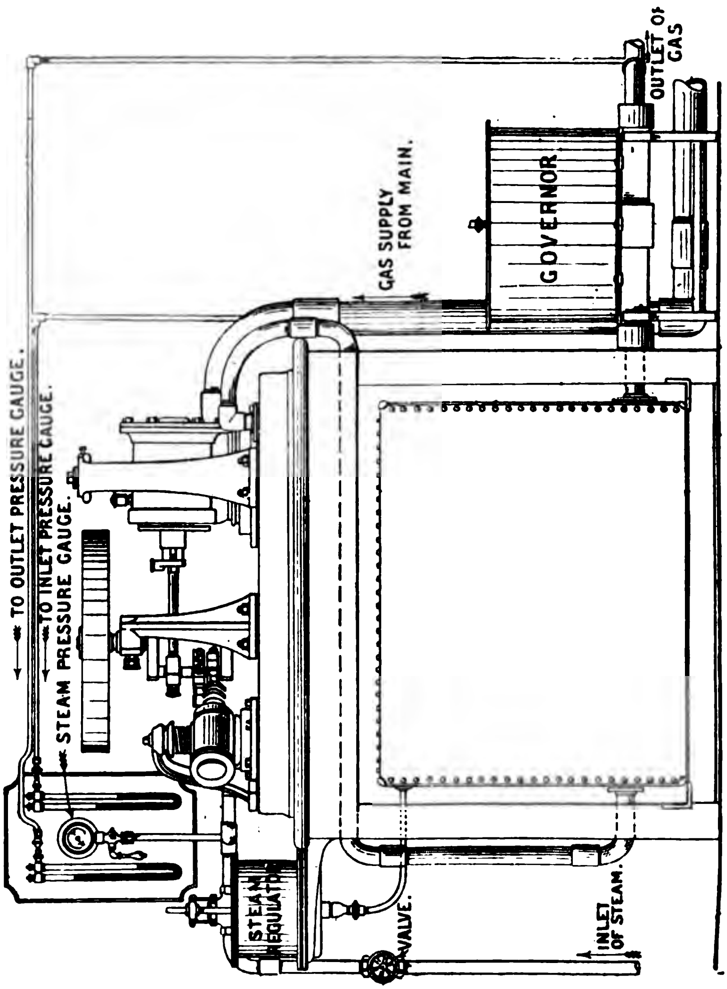


Fig. 109.—Steam Pressure Increaser—Elevation.

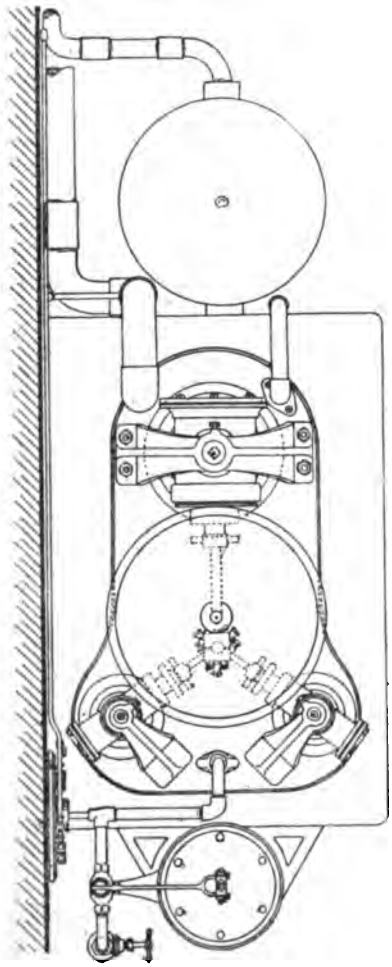


Fig. 110.—Steam Pressure Increaser—Plan.

be made. Figs. 109 and 110 show the apparatus, which is composed of a double-cylinder steam engine working a gas pump. The speed of the engine is controlled in the same way as the water engine, by a regulator, which is worked by the pressure of gas coming from a receiver shown under the bench, which serves as a gasholder or reservoir of gas; and, as in the water apparatus, prevents the shock of the gas when released from each end of the cylinder of the gas pump from affecting the lights, which is finally controlled by a governor on the main service, or at different points where the burners are in use.

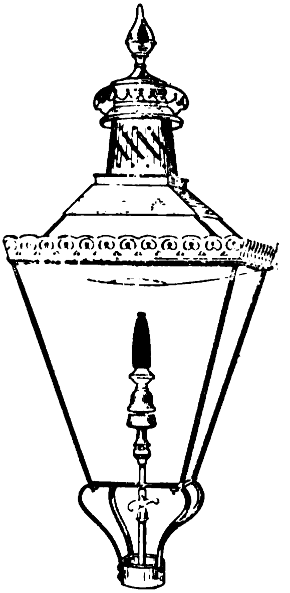


Fig. 111.—18in. Victoria Lamp.

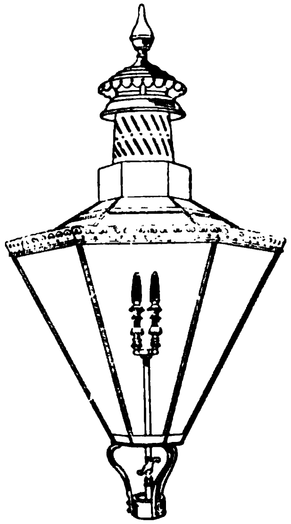


Fig. 112 —28in. Lambeth Lamp.

Another apparatus is made by the same firm, which is driven by a band from the shafting of the machinery in a workshop or by a gas engine, and which will supply from 50 to 150 lights, according to the speed of the shafting and the size of the workshop or premises which it is to light

From the pressure-increasing apparatus the gas passes into the service which supplies the burners or lamps.

High-pressure Street Lamp.—Fig. 111 represents one of Messrs. Sugg's patent "Victoria" lamps, with one 10ft. burner in it, giving a light of 300 candles nominal.

Fig. 112 shows one of Messrs. Sugg's patent "Lambeth" lamps, fitted with two burners, and giving a light of 600 candles nominal.

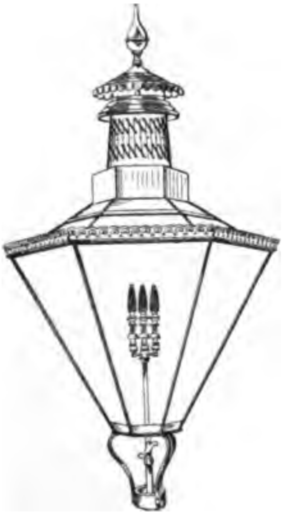


Fig. 113.—44in. Lambeth Lamp.

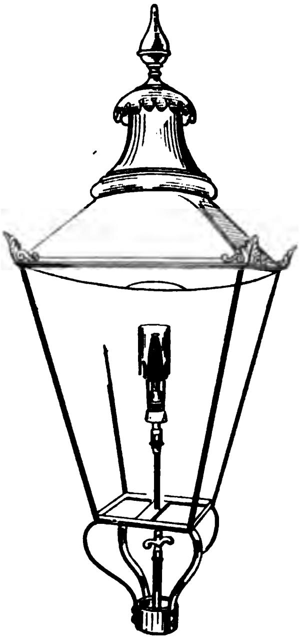


Fig. 114.—16in. Windsor Lamp.

Fig. 113 is another "Lambeth" lamp, constructed to carry a cluster of three of their burners, and giving a light of 1000 candle-power nominal.

Sugg's patent "Windsor" lamp is shown in Fig. 114, and is the latest development in low-pressure incandescent lighting. It has been adopted for the lighting of the Castle and the Home Park, Windsor, the grounds of

Buckingham Palace, and by H.M. Commissioners of Woods and Forests for lighting Regent's Park; by the Borough of Hampstead; by the South Metropolitan Gas Company for public lighting; and a number of towns in the provinces.

The ventilation of this lamp has been very carefully studied, and in consequence of the improvements effected, it enables the incandescent burner to produce a much higher result per cubic foot of gas consumed in the lamp than the burner does out of it, and the mantles, being better protected from draught and supplied with warm air, will last longer, it is claimed, than in any other lamp.

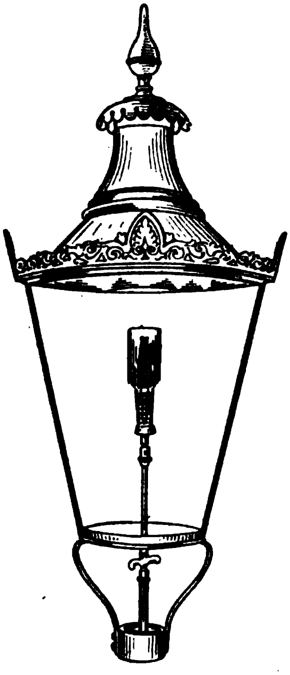


Fig. 115.—16in. South London Lamp

The South London lamp, Fig. 115, is a lamp designed especially for the lighting of the public streets and roads in the South Metropolitan Company's district. There is a special arrangement in this lamp, which is patented by the South Metropolitan Gas Company, by which the objectionable obstruction of the light by the bars of the lamp, which generally cast a shadow across the road, is avoided by a very simple arrangement of the glass, with the effect of throwing the shadows obliquely on to the footway, thus securing uninterrupted illumination of the roadway.

This system of lighting is of great brilliancy, whiteness, steadiness, and volume, and therefore well diffused. In Whitehall there are ten 1000-candle "Westminster" lamps, whilst all the refuges from the Church of St. Mary-le-Strand up to the City Boundary are lighted with 1000-candle "Westminster" lamps. Ludgate Circus is also lighted with six 1000-candle "Lambeth" lamps with a new kind of reflector. Blackfriars Bridge approach is lighted by two 1000-candle "Lambeth" lamps of the same pattern as those used at Ludgate Circus. Tower Bridge, Southwark Bridge, Blackfriars Bridge are all lighted with lamps with one 10ft. burner, high-pressure gas, which gives 300 candles nominal light. The high-pressure lighting has proved a great success in this country, and has been largely introduced abroad, it being particularly suitable for railways, docks, shops, harbour ports, gasworks.

Fig. 116 illustrates one of Messrs. Sugg's high-pressure incandescent burners, to burn 10ft. an hour and give a light of 300 candles nominal, with a pressure of 9½in., under the inlet of the burner. By increasing the pressure under the burner to 14in., and consequently the consumption to 12½ft., the illuminating power given by the burner is 400 candles nominal instead of 300. It is remarkable that this extra consumption of 2½ft. per hour adds to the light given by the burner as much as 40 candles per cubic foot of gas consumed. The top of the burner upon which the gas is consumed, and the nipple at the bottom of the burner which regulates the quantity of gas supplied to the burner, are made in steatite ; consequently both are unalterable by damp or rust or the heat of the combustion of the gas. Each burner is also provided with an anti-vibrator spring, which prevents vibration of traffic from breaking the mantles. The burner is also made so that in case of stoppage in the service pipe or the lamp by napthalene, the top part of the burner and the mantle can be lifted off and put down in the corner of the lantern whilst the service is being blown out, and can be replaced without doing any damage to the mantle. There is a governor for this burner, to be used for public lighting when no meter is fixed, to regulate the quantity of gas and maintain it at 10ft., or other quantity contracted for. In workshops where one pressure-increasing engine supplies different floors, the same pattern governor is used to keep the different floors at a constant consumption.

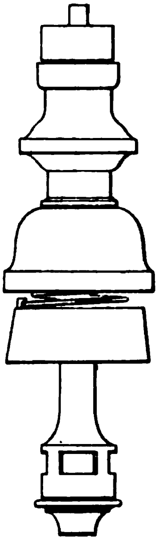


Fig. 116.—High-pressure Incandescent Burner.

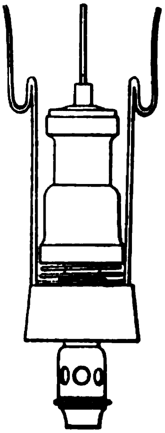
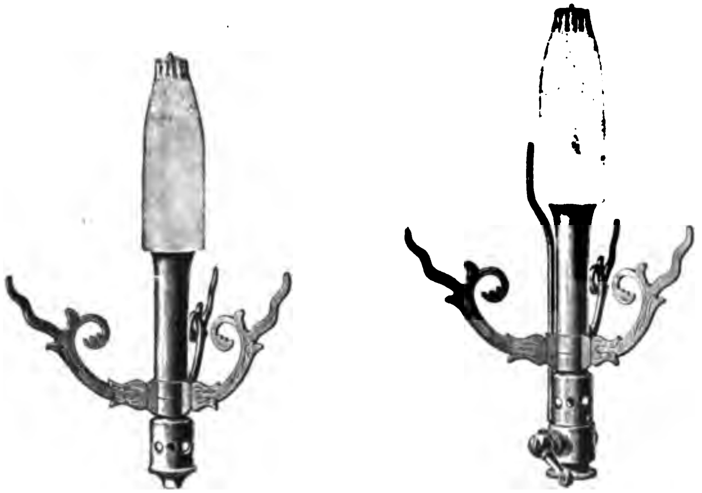


Fig. 117.—Low-pressure Incandescent Burner.

The smaller burners for low-pressure street lighting are illustrated by Fig. 117. They consume 3½ft., 4ft., and 5ft.

per hour, giving each respectively, the first 50 candles, the second 70 to 80 candles, and the third 110 to 120 candles, according to the quality of the mantles.

Messrs. Sugg and Co. lay great stress upon the construction of the burners, which are cast in yellow bronze, no stamp work of any kind being used, hence the perforations for the air will always remain free and open, ensuring the satisfactory working of the burners at all times, and preventing the rotting of the brass by the action of the air of towns or the salt of the sea.



Without By-pass. With By-pass

Fig. 118.

Messrs. Sugg and Co.'s adaptation of the incandescent mantle system of illumination to domestic use is illustrated by Fig. 118. These burners are arranged to take the well-known "Christiania" globe. No. 3 size burner affords a light equal to 65 candles, and No. 4 equal to 120 candles.

CHAPTER XIII.

SELF-INTENSIFYING GAS PRESSURE.

The Lucas Incandescent Intensive Gas Lamp.—Fig. 119 shows the Lucas principle. The lamp from the base of the burner to the top of the extending chimney is a continuous cylinder. The burner is 7in. in length and the air chamber is about 1¼in. in diameter. The mantle, which is fitted over the top of the burner, is about 6½in. in length, and is suspended by a nickel wire rod. The globe which surrounds the mantle rests on a suspended ring at the top of the burner, and fits in a flange at the lower end of the extended chimney.

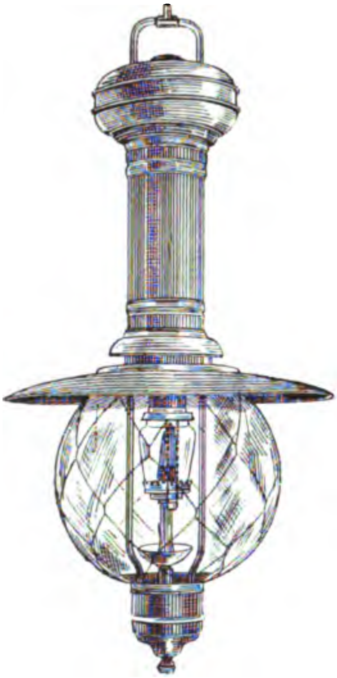


Fig. 119.

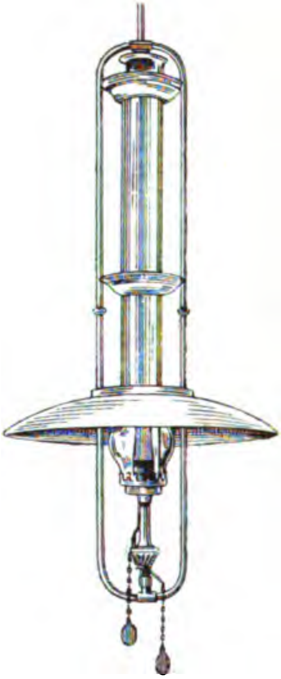


Fig. 119a.

As soon as the gas is turned on and is ignited by the by-pass, the air in the globe becomes heated, and has a tendency to rush up through the metal chimney, thus causing an induction of air at the base of the burner, which, mixing with the gas supply, passes through the mantle, so that all of the gas and all the air introduced at the base of the burner is forced through the mantle.

The gas consumption is stated to be 17½ cubic feet. The lamp is so constructed that this rate of consumption, with the air admitted to the lamp, gives the most perfect combustion. In cases where the pressure of the gas is above 1½in., it is found necessary to use a regulator in order to restrict the flow of gas; and where the pressure is below 1½in., the gas is regulated to the burner by the apertures of the nipple.

Scott Snell System.—The following account of Mr. C. Scott Snell's system of self-intensifying gas pressure is abstracted from the "Proceedings" of the Incorporated Gas Institute, the blocks of illustrations being inserted by the kind permission of the Council:—

The necessity for means of attaining pressure in the lamp itself was recognised soon after taking up the study of intensified gas lighting. The compressor system involved a plant or equipment, and therefore caused an initial outlay which necessarily limited its sphere of application. Upon considering the selection of a force available to operate any intensifying appliance, waste heat was certainly obvious, and possessed the advantage of being free of cost; while neither drought nor frost would effect its efficiency.

An appliance was required which should receive gas at normal pressure and deliver it at an increased pressure of 8in. of water or more. (1) It must be operated by waste heat. (2) It must require no lubrication. (3) It must not have a dead centre. (4) No fly-wheel, slide valves, connecting-rods, packed glands, or friction-producing appliances must be included. (5) It must be self-controlling. (6) Its cost must be low. (7) It must be simple in construction and easily adjusted.

Mr. Scott Snell concluded that an invention using heat as a motive power was bound to include a displacer movement, as in every hot-air engine; and where two different pressures of gas were necessarily involved (a low inlet pressure and a high outlet pressure), check valves were essential. It was easy to see that, by the movements of a displacer within a vessel heated at one end and cooled at the other, gas or air could be drawn in at one check valve and ejected at the other, provided some practicable agency could be found to operate the displacer.

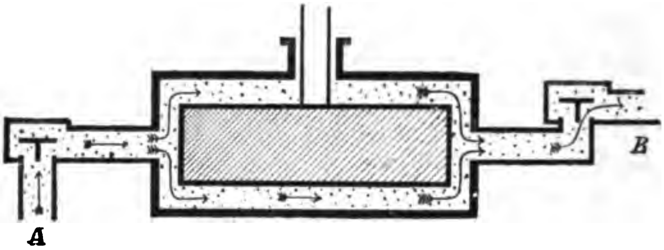


Fig. 120.

Showing displacer chamber with check valves, no heat applied, reciprocation of displacer has no effect on gas.

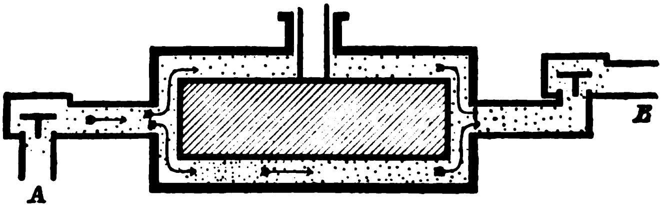


Fig. 121.

Showing displacer at half stroke and heat applied to base of chamber. A film of cold gas passes over the top of the displacer and a film of hot gas passes under the displacer, but equilibrium of pressure is still maintained.

The conditions under which the apparatus operates are as follows:—The vessel is charged with gas, one-half of which (the upper) is at a moderate temperature—say 80° Fah.—the lower half being perhaps at 500° Fah.

Fig. 120 shows a displacer chamber viewed when gas is going through, but no heat applied; the displacer movement therefore produces no effect on the gas. Fig. 121 shows the displacer at mid-stroke. Figs. 122 and 123, with the notes appended, illustrate the conditions which follow the movement after heat is applied. Fig. 125 illustrates essentially the conditions which obtain when a diaphragm is attached to the displacer rod and made responsive to the variations in pressure in the chamber.

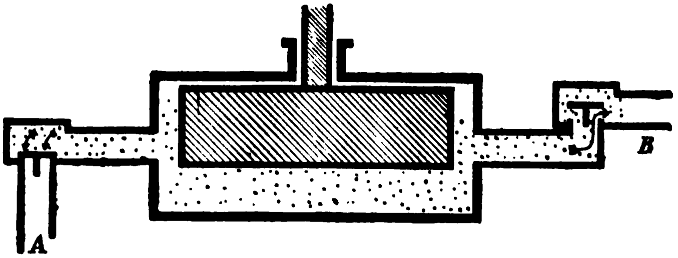


Fig. 122.

Displacer raised, gas transferred to hot section. Expansion closes valve A, and drives gas out at B.

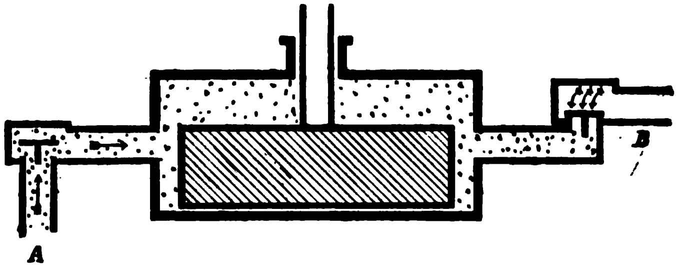


Fig. 123.

Displacer depressed, gas all transferred to cold section. Contraction causes partial vacuum, gas rushes in at A, while B is closed by back-pressure.

With the construction shown in Fig. 124 the action may be readily followed. For clearness, let it be assumed that the displacer is slightly, yet quickly, lifted. It follows that a quantity of cold gas is added to the heated section and caused to expand. Such expansion stops the inflow from the gas supply, by reason of the rise of pressure acting on, and closing, the inlet valve; it also

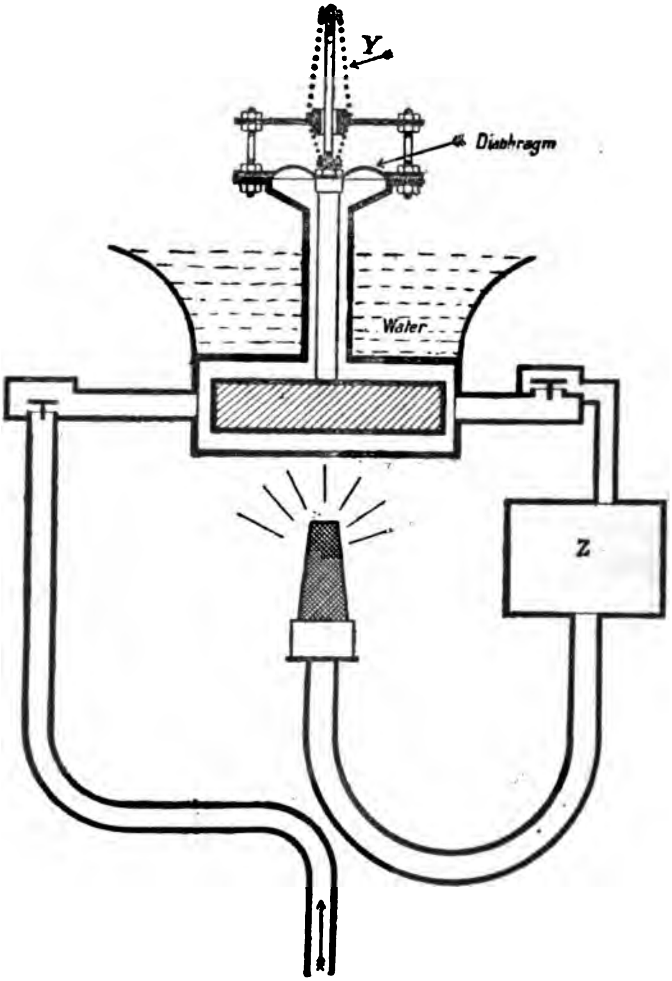


Fig. 124.

causes a blow-out through the outlet valve. Most important of all, its effect is felt on the diaphragm, which, by its consequent movement, still further lifts the displacer, and drives more cold gas down to the hot side. This, therefore, by expanding, causes the initial lifting power to be reinforced, until a full stroke or travel is attained. As the gas, after passing the outlet valve, goes to the pinhole in the nipple, the rate of discharge to the atmosphere is comparatively limited, and pressure therefore increases rapidly in the intervening pipe and reservoir.

At the beginning of the upward motion of the displacer, the spring to which it is attached counterbalances gravity, but towards the end of the upward stroke the spring has ceased to do so to any great extent. A point is therefore reached where the loss of assistance from the spring allows gravity to assert itself until it exactly equals the lifting power on the diaphragm. This would mean stoppage of further movement, and be equivalent to a "dead centre;" but the momentum of the displacer coming into play causes the travel to extend beyond such a critical counterbalancing position. At this point the peculiarity

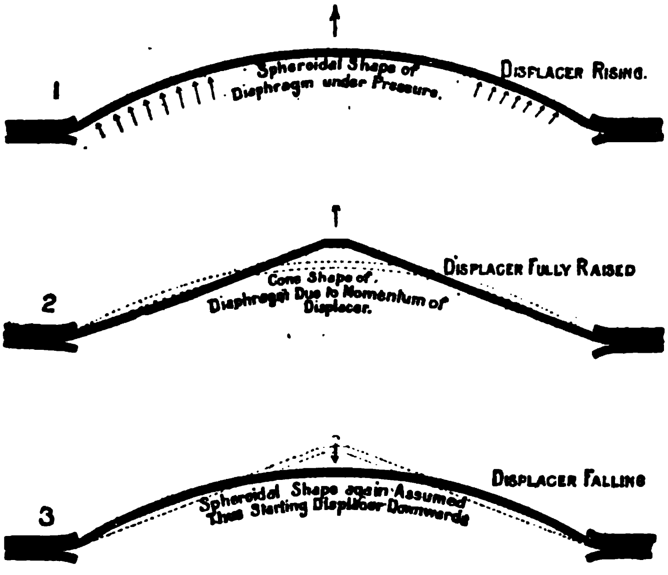

1
Spheroidal Shape of Diaphragm under Pressure.
Displacer Rising.
2
Cone Shape of Diaphragm Due to Momentum of Displacer.
Displacer Fully Raised
3
Spheroidal Shape again Assumed Thus Starting Displacer Downwards
Displacer Falling

Fig. 125.

of the diaphragm has to be considered. It was in a position giving maximum lifting area at half-stroke; but its effect becomes rapidly diminished as it blows out. So that, as the displacer lifts, not only is the counterbalancing effect of the spring becoming more feeble, but the effective area of the diaphragm is also diminishing; hence the displacer, once in motion, will always travel beyond the point of equilibrium of the various forces, on account of its momentum. The reaction, when the momentum is exhausted, is that due to gravity; and the displacer will naturally tend to fall back to such a point that the effective area of the diaphragm, multiplied by the pressure in the vessel, would counterbalance the gravity effect, or such amount as the spring in that particular position may fail to sustain.

This point, if reached in practice, would mean, as it were, a "dead centre" on the down stroke. But such a trouble is avoided, because, when the displacer commences to fall, it also begins to transfer a part of the heated gas below it to the cold section above it, thus starting condensation and rapidly reducing pressure until a partial vacuum is set up, which increases in intensity as the displacer falls. Therefore, not only has the upward pressure on the diaphragm been destroyed, but a positive downward atmospheric pressure, tending to depress the displacer, has been substituted, which rapidly drives down the displacer to its utmost limit. In being so depressed, however, the displacer is causing abnormal compression of the sustaining spring, until its momentum becomes absorbed thereby. The diaphragm at the same time, by its motion below mid-stroke, is lessening in effective area, and therefore in depressing power. Another result also taking place at the same time is that the condition of partial vacuum set up by the depression of the displacer is causing a rapid influx of gas through the inlet valve, which quickly overcomes the vacuum and relieves the diaphragm of atmospheric pressure.

The displacer at its ultimate downward limit is therefore subject to the following conditions:—There is no downward force on the diaphragm. On the contrary, the influx of gas, at the pressure of the gas main, is tending to lift it. Further, the spring, being abnormally compressed, is also tending to lift the displacer back to mid-stroke. All forces have therefore become reversed in direction, and a lifting power is in operation. Upon its way back to mid-stroke, at which the displacer would nominally come to rest, it causes a transfer of cold gas above it to the hot section below, and therefore the diaphragm, with an increasing effective area to act upon, is made subject to upward pressure, and the cycle repeats itself. The movement is therefore due to a sort of "hunting" effect, and results in a reciprocation of the displacer, at the rate of 120 cycles (up and down movements) per minute.

Such an apparatus as described constitutes a reciprocating engine which (1) has no piston, yet compresses the contents of the gas chamber; (2) has no slide valve, yet preserves a perfect cycle; (3) has no fly-wheel, yet cannot stop on a dead centre; and (4) has no governor, yet accommodates its beat to the demand for gas. This last advantage is of very considerable importance; the rate of reciprocation being, in fact, according to the size of the gas nipple. For instance, a lamp may have but one burner and have a rate of 120 cycles per minute; but if three nipples be used, as for cluster work, the lamp will operate with greater rapidity, delivering three times the volume of gas, and, of course, it will have the waste heat from the three burners to energise it. Here it is interesting to note that the size of displacer, 6½in. diameter by ¾in. stroke, at present in use for one burner will supply three burners if needed.

When a heavier valve, which will not allow gas at the normal pressure of the mains to find its way to the nipple by passing through the displacer chamber, is used, an appliance called a "reverter" is employed. It may, in brief, be described as an automatic bye-pass, whereby the Bunsen burner is heated by low-pressure gas until the intensifying commences, after which the lamp runs on high-pressure alone. The effect of heavy valves is as follows:—When the lamp is cold, the displacer chamber necessarily contains an initial charge of either gas or air at atmospheric temperature. On heat being applied to the bottom of the chamber, the expansion caused thereby increases the pressure to an extent determined by the weight of the outlet valve; and it is this pressure transmitted to the diaphragm which, of course, causes the displacer to be raised, and thus begin the cycle of movements already explained. Valves, if allowed to get dirty, prevent this initial pressure being achieved, on account of want of tightness. Such neglect does not prevent the lamp being started, as will be explained later on; but self-starting becomes spoiled.

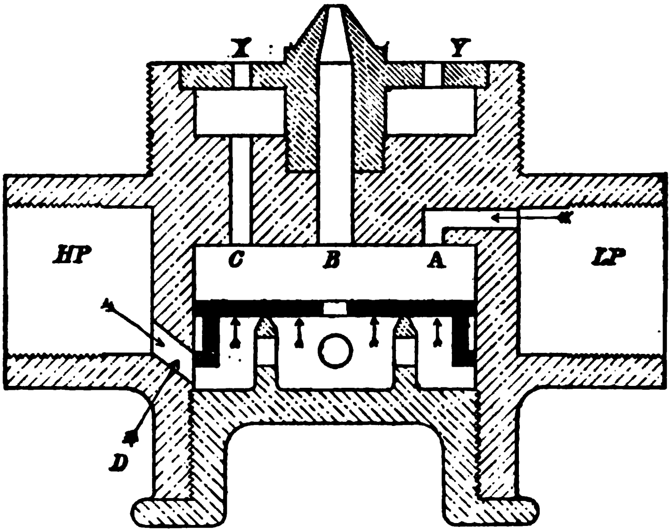


Fig. 126.

Referring to the reverter (Fig. 126), gas at low pressure enters at A, and, the float being down, finds an exit up the centre hole B and the side hole C. From the latter, it issues at the side apertures X and Y. The total gas aperture area for low pressure therefore consists of the openings X, B, and Y; and while B is a standard aperture, and must not be touched, X and Y may be

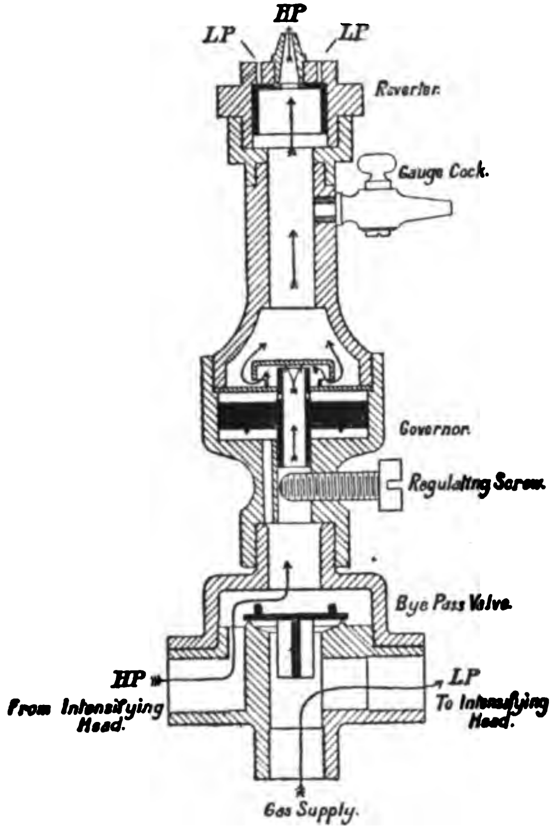


Fig. 127

opened out, if necessary, to suit a very low local gas pressure for the lamp, when in use as an ordinary low pressure lamp. A channel D makes a connection (under the float) with the high-pressure pipe; and when the heat has taken effect on the intensifying chamber of the lamp above, to which the pipe is connected, the cycle commences, and delivery under pressure ensues. The rapid flow of gas which follows lifts the float and closes the low-pressure aperture A, as well as the hole C, whereby only the standard opening B is left at work. Should the lamp cease its action from any cause, or be cut off by a special tap provided on the lamp, and the supply of high-pressure gas cease, the float will fall, thereby re-starting the supplementary feed apertures, and maintaining a good light, even at low pressure. The aperture B alone would give but a small light, and take rather longer than desirable to heat up and start the lamp, if not supplemented by the feed from the additional holes X and Y.

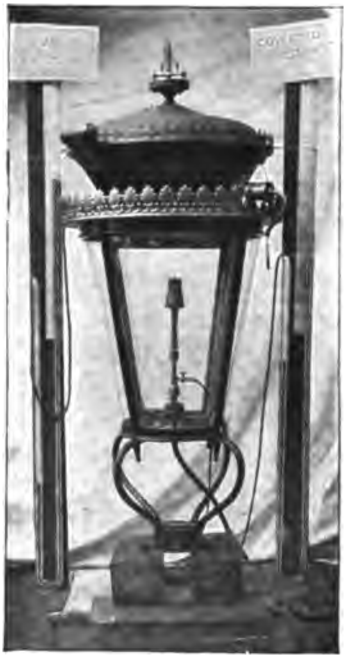


Fig. 128.

Photograph of lamp actually running, but without mantle. Governed pressure, taken by gauge attached to cock between governor and nipple, 8¾in. Pressure in lamp reservoir, taken by gauge attached to cock at head of lamp, 27¼in.

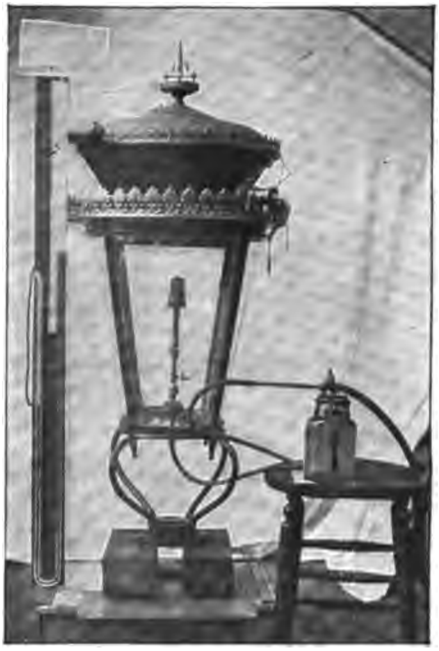


Fig. 129.

Photograph of lamp actually running, but without mantle. Gas enters water seal by the large rubber pipe ending in a vertical tube to bottom of glass jar. Lamp is sucking through thin metal pipe projecting horizontally and sealed into head of jar. A bye-pass valve cuts out the water seal to admit of temporary gas supply for starting lamp. This is then closed, and the lamp draws through the seal. The gas-supply pressure is 2in., water seal 4in. deep, actual water sealing therefore 2in. Lamp-gauge is reading 13in.

The form of reverter above described has been modified to admit of easier attention to internal parts, which has been effected by subdividing its functions. The bye-pass arrangement is worked by a separate disc apart from the float (see section in Fig. 127). It will be noticed that the governor stands immediately over the bye-pass valve, and the "aperture controlling float" is immediately under the burner, the whole being in one vertical line. They may be replaced or examined very easily by unscrewing the top of the bye-pass valve and removing it with all the appertaining parts mounted upon it. A point not to be overlooked in burning heated gas is that the nipple area requires adjustment. For instance, gas at 250° Fah. temperature will be expanded probably 30 per cent. over its original bulk when it was admitted to the lamp. The nipples therefore require slight enlargement over cold gas nipples. This admits of greater velocity of delivery, and therefore a sharper blast for drawing air into the burner.

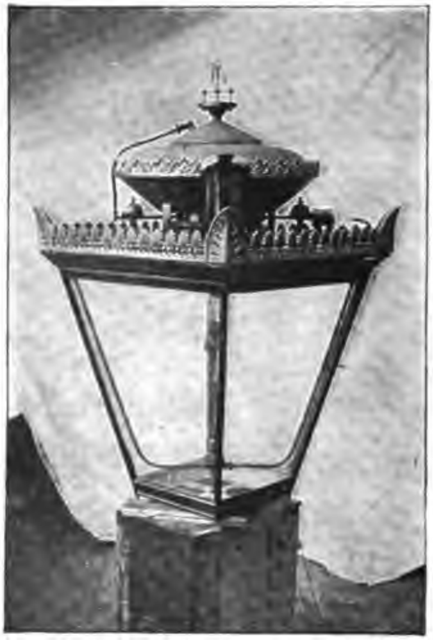


Fig. 130.

Elevation of lamp in square lantern, showing inlet valve with starting device on one side, and outlet valve with connection to reservoir on the other side.

A water-charged head to each street lamp is maintained in an extremely simple manner. A hollow shepherd's crook is hooked into the water-filling aperture, and by rubber attachment to a hand pump the water is delivered until it overflows. By such an appliance, and the use of the municipal water-cart, it would take very little time to charge 100 lamps.

It has been pointed out that dirty valves may prevent a lamp automatically starting. The possibility of dirty valves is due to the heated gas in newly-made lamps vaporising the grease in the pipe joints, which are made with graphite; but this disappears in due course—the lamps, in fact, improve by use. Each lamp is provided with a starting device, which enables the attendant, by pulling a light chain, to cause a pulsation of the gas in the displacer

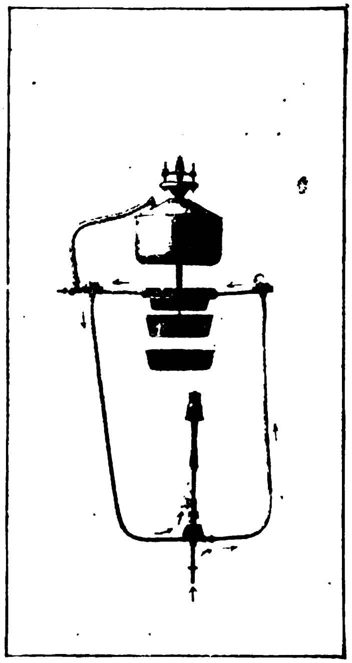


Fig. 131.

Rough skeleton of lamp (lantern reflectors, &c., removed) showing simplicity of vital organs. Arrows show course of gas through pipe to inlet valve, onward to intensifier, out through outlet valve, and down to burner. Connection to reservoir above is also shown. The hot dish is suspended over the burner, the displacer dish which nests into it is shown immediately above, and the cold dish, which also rests into displacer, is shown with valve pipes attached. When the hot and cold dishes are clamped flange to flange, the displacer has a vertical movement of about ¾in.

chamber; so that the lamp then enters into the intensifying stage, if sufficient heat has accumulated at its base. Some of the lamps have been put to the test of continuous operation day and night for 160 consecutive hours, besides subsequent runs of 128 and 123 hours continuously, and the interior has then been found in good condition, no deposit of naphthalene being discovered. Indeed, it appears doubtful if such could exist in a lamp where the general temperature is so much above the normal.

As evidence of the extent of improvement effected in gas lighting devices, it is of interest to note that the step up from a 15-candle power batswing burner giving 3 candles per foot to a self-intensifying lamp giving 540 candles from a single burner is as follows:—The efficiency is increased 12 times. The unit of light is increased 36 times. These results are of some significance in the competition with electricity. Expressed in other words, it may be said that gas enters the lamp having a value of 2s. 6d. per 1000 cubic feet; but the light attained gives such service that it is equivalent to reducing the price of gas to 2½d. per 1000 cubic feet.

The Kitson Light.—One of the most recent developments of the system of lighting by incandescent mantles is that invented by Mr. Arthur Kitson, of Philadelphia, U.S.A., and now of London. An installation on this system consists of three essentials, viz., (1) the reservoir, containing petroleum oil, having a flash point of about 100° to 120° Fah. (Abel test); (2) the lamp; and (3) the tubing conducting the oil from the reservoir to the lamp. A vapour tube passes over the burner, and the oil is thereby vaporised and converted into an oil gas, in which form it is consumed in contact with the mantle.

The oil, reaching the lamp cold, through the tubing (1) (Fig. 132), is conveyed to the vaporising tube (2), which in diameter is the size of a lead pencil, and 8in. long, and is there gasified by the heat from the mantle (3), the arrangement being such that only a minute quantity of oil contained in the vaporising tube is subjected to the heat at one time. An indication of the smallness of the consumption is here afforded by the minuteness of the outlet (4) at the opposite end of the vaporising tube, it being no larger than a needle-point. From thence the oil vapour passes into an open mixing tube (5) on the top of the reflector, where sufficient air is drawn in for supporting combustion. The mixture then travels down to the mantle, inside which it burns.

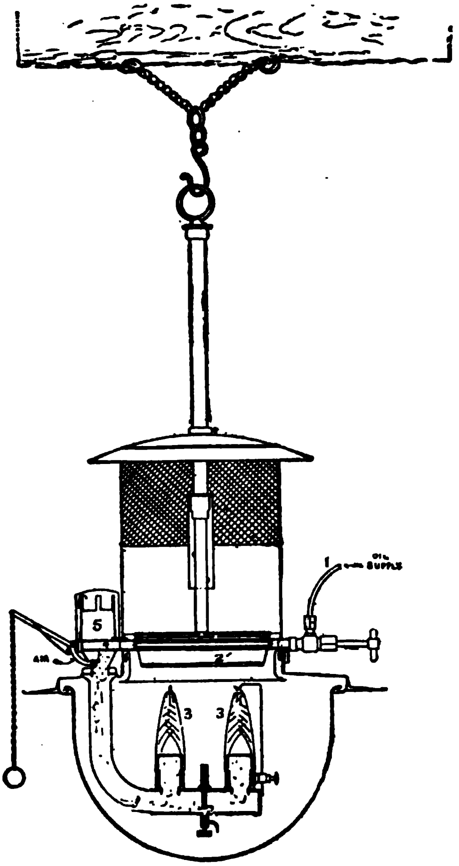


Fig. 132

The lamp is lighted by a very simple and ingenious contrivance, which rapidly heats the vaporising tube previous to the turning on of the oil.

The reservoir or oil storage tank (Fig. 133) is a strong, though light, cylindrical vessel, constructed of cold-drawn steel, with oil and air capacity varying from 5 to 40 gallons, which is equal to 1000 candle-power for 15 to 150 hours respectively, and may be placed in any convenient cellar or underground.

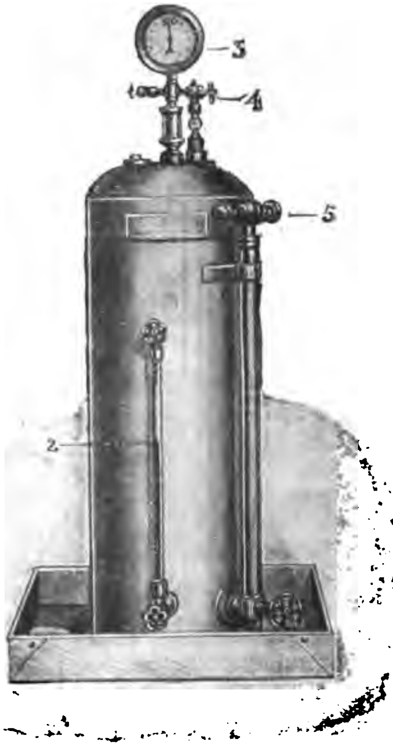


Fig. 133.

By means of the pump the tank is first charged with oil, then air is pumped in up to 50 lb. gauge pressure, which air lasts for all time. All that is then needed to keep up the pressure is to replenish the supply of oil when it is becoming exhausted.

In Fig. 133 (2) is the sight gauge, indicating the depth of the oil in the tank; (3) pressure gauge; (4) safety valve; and (5) a simple oil pump.

The oil is conducted by strong copper or bronze tubing, the bore of which is no larger than electric incandescent wires, which tubing is easily manipulated and hidden from view. It may ramify to any number of lamps, but it is not advisably carried beyond 1000ft., as it would then cost less to install another reservoir.

The oil flow is controlled by means of:—(1) Ordinary taps in suitable positions, operated similarly to gas taps. (2) Automatic check valves, which immediately stop the flow of oil in case of accident to any part of the tubing. (3) The passage of oil is automatically increased or diminished according to the light in use.

The Kitson system of lighting, which is applicable to domestic as well as public use, was originally invented in the years 1885 to 1889. But until the mantle industry had become developed it was impossible for the petroleum incandescent light to attain commercial success.

CHAPTER XIV.

ANTI-VIBRATORS.

Before the introduction of the "anti-vibrator," the incandescent gas light was hard put to it to maintain its position for street lighting, but the invention of methods for preventing the jar of the traffic being communicated to the mantle placed the whole question on a different footing.

Amongst those which appear to be most satisfactory is that devised by Professor Robert Smith. This device consists essentially of a conical or cup-shaped hollow piece of metal, across the base of which is clamped one or two thin non-metallic flexible sheets or diaphragms, of a material impervious to gas, and having a low modulus of resilience. Either the tap is attached to the centre of the flexible sheet or sheets, and the burners to the metal cup, or else the burner is fastened to the centre of the sheets, and the tap to the metal cone. The material of the flexible sheets is of such kind as is unaffected to an injurious degree by contact with gas or by such heat as reaches it by conduction or radiation from the burner supported above it.

In some descriptions of lamp a thin sheet of vulcanised rubber, with or without canvas webbing, serves the purpose; but when the disc is exposed to a higher temperature what is known as "asbestos sheet," with or without rubber, canvas, or metallic webbing, is more suitable. This material, in the form of thin sheets, clamped at their edges only, has also the advantage of transmitting less vibration than does rubber. Other materials may be used for the flexible discs in such cases as they may be required.

The metal cone or cup may be placed with its broad base and the flexible sheet or sheets at the top, but the inventor generally prefers the inverted position with the

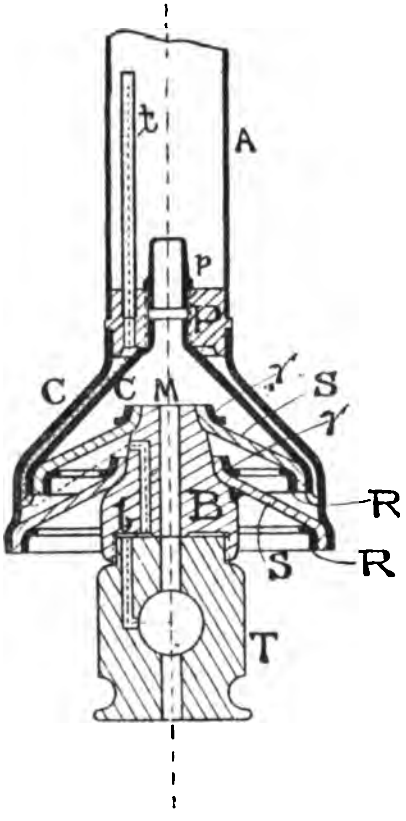


Fig. 134

base downwards. The cup may be cylindrical, or other shape preferred.

The sheets when unloaded may be flat, but when carrying the weight of the superincumbent parts they are drawn into a more or less conical shape by this load. This conical shape is that desired, as being more efficient in insulating from horizontal as well as from vertical vibrations than would be the flat form; and in some circumstances it is desirable to mould the sheets with a considerable degree of initial conicity instead of to the flat form.

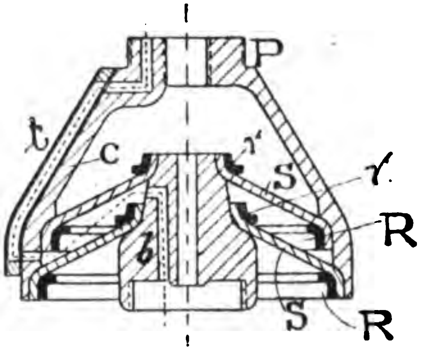


Fig. 135.

In Fig. 134 is illustrated the form in which a double cone C C, with base downwards, is used. Fig. 135 shows a modified construction in which one cone, C, only is used. Fig. 136 shows a construction in which the base of the cone C lies at the top.

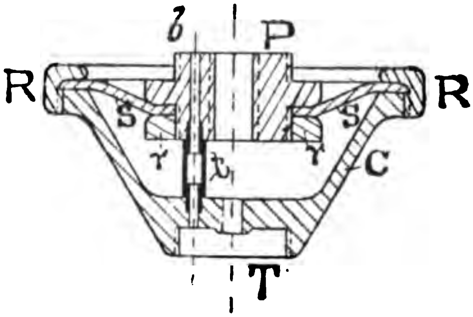


Fig. 136

This anti-vibrator has been subjected to the most rigid tests by Mr. Stephen Carpenter, manager of the works of the Sutton Gas Company, from whose report to Prof. R. Smith the following extracts are taken :—

After some preliminary experiments to decide the most efficient form of test apparatus, one of your anti-vibrators was on 29th March, 1899, fixed on the top of a ½in. gas pipe rising vertically 4ft. 9½in. from the floor of our boiler-house alongside of a vertical donkey feed pump. At 3ft. 3½in. from the ground a hardened tool-steel arm was clamped horizontally on this pipe, its length to the striking point being 6in. At about 3ft. 6in. from the ground the ½in. pipe was lightly lashed to a thin lath nailed to the wall in order to limit the throw of the vibration. This lashing made the shocks sharper, although it diminished the range of the horizontal throw. It in no way affected the vertical component of the shock, nor the total energy of each blow.

To the fly-wheel of the pump was rigidly secured a hardened tool-steel arm 14in. long. When this arm reached 45° from the vertical on each down-stroke it struck the other 6in. arm clamped upon the upright stem-pipe. The end of the striking arm overlapped the other by ¼in., so that the latter had to be forced aside ¼in. to allow the striking arm to pass. During the 1,848,000 *blows* delivered, the horizontal arm, which was of hardened tool-steel, wore away $\frac{1}{32}$in., while about 1,300,000 blows wore away the end of the striking arm ⅛in. The amount of overlap was adjusted from time to time to regulate the strength of the blow.

The above 1,848,000 blows did not in any way pull out or loosen the edge joints of the flexible diaphragms, or any other joints of the anti-vibrator. In this number of blows are included those given in the intervals between the tests of the different mantles used.

A Welsbach C burner with ordinary glass chimney was fixed on the top of the anti-vibrator.

March 29th.—A new perfect Welsbach mantle was placed on the ordinary forked rod, and burnt off, smoking slightly at base where touching the burner. Started blows 9 a.m., and continued them until 9 p.m., March 31st, at an average speed of 140 shocks per minute, giving *total number of blows* 504,000. The mantle was still perfect, but the test was interrupted by the striking arm being broken by the violence of the repeated blows. A new striking arm was fixed, and the test recommenced at 9 a.m., April 1st, with the same mantle, and a somewhat stronger blow than before. At 4 p.m. the mantle was still perfect, having then received 562,800 *blows*. The machine was then required for other purposes, and the testing mechanism disconnected. The attendant having omitted to remove the mantle, it was broken on the occasion of the pump running away, and causing very violent shock and oscillation throughout the loose disconnected parts.

April 5th.—At 3.45 p.m. a new perfect Welsbach C mantle was mounted in same manner, but *without the anti-vibrator*, with the same strength of blow as the last. The pump was started gently, and its speed increased gradually. The mantle *broke off near the top at 70 blows.*

April 5th.—At 4 p.m. the anti-vibrator was refixed as before, and a new Welsbach C mantle suspended and burnt off. This test continued uniformly from this time till 6 a.m., April 10th, when the mantle was still perfect. The average speed was 100 shocks per minute, and the time being 110 hours, the *blows received were* 660,000.

The author has specially tested this anti-vibrator, and finds that it causes no depreciation of the intensity of the light, whilst the enhanced life of the mantle was most remarkable, thus completely confirming Mr. Carpenter's results.

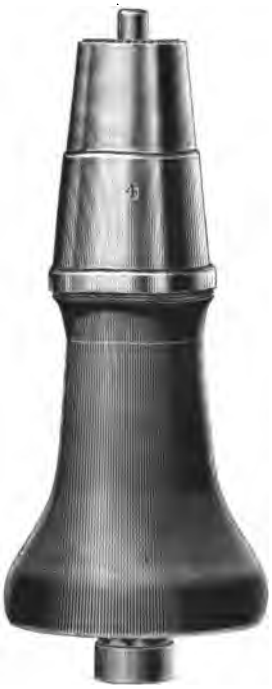


Fig. 137.

As an indication of the practical value of this anti-vibrator, the following experience may be recited:—In August, 1900, an ordinary C Welsbach burner, with Prof. R. Smith's anti-vibrator, was fitted under Mr. S. Carpenter's directions in one of Messrs. Greene and Co.'s lanterns in Cheam Road, Sutton, Surrey. At the present time, after twenty months' use, the *same* mantle continues to afford a satisfactory light. The anti vibrator is one of the first that was made.

Welsbach Kern Burner and Anti-vibrator (Fig. 137).—The illustration shows the Kern burner fitted with the patent anti-vibrator supplied by the Welsbach Company. This form of anti-vibrator has been successfully used in street lighting, in the lighting of railway stations, factory workshops, &c., and it is claimed that by its adoption Welsbach mantles are enabled to withstand the severest shocks and most sustained vibration. The anti-vibrator consists of a bell-shaped metal weight supported by a spiral spring, which takes up the jar of both lateral and vertical vibration.

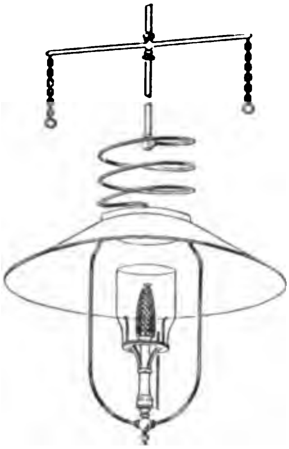


Fig. 138.—Harwich Anti-vibrating Suspension Fitting.

Fig. 138 is a drawing of a simple fitting with a steel tube anti-vibrator and an enamelled reflector, constructed by Messrs. Sugg and Co. for use in workshops, &c.

CHAPTER XV.

LAMP GOVERNORS AND AVERAGE METER SYSTEM.

Lamp Governors (1866 *Model*).—(A), Fig. 139, is a steatite burner tip, and the diagram shows the method by which it is fastened into the cone (B), which is screwed to the governor by an ordinary $\frac{3}{8}$ gas thread. The best burner for the purpose, and the one that is now almost universally adopted, is the table-top.

(C) is a metal ring, which, being screwed into the body of the governor, holds the leather firmly to its seat. Between the leather and the metal ring is a turned card washer, which prevents the leather from being injured by the turning of the screw in tightening it down to its bearing.

(D) is the regulating valve fixed to the leather (E) by means of two shields (F F), which clip the leather between them, these shields being held firmly by a screwed brass nut (G) on the top of the upper shield, and a tin washer on the underside of the lower one. The leather (E) answers the same purpose in the dry as the gasholder does in a wet governor, rising and falling accordingly as the pressure is more or less at the inlet (L).

(H) is the junction gasway connecting the outlet of the lower part of the governor to the cover through which the gas passes up the cone (B) to the burner, in the direction shown by the arrows.

(I I) are screws which hold the gasway to its seat. Between the gasway and the seat is interposed a washer made of paper, which, being painted with a little red lead and oil, secures the soundness of the joint.

(K) is a screw for holding the top securely and preventing damage to the gasway should the lamp-lighter strike the cone too hard with his torch in lighting, or catch the burner with his sleeve in cleaning the lantern.

(L) is the inlet of the governor screwed to the ordinary $\frac{3}{8}$ gas thread, and the direction of the gas is shown by arrows.

(M M) is an annular leaden weight by which the pressure to be maintained at the point of ignition is fixed. As in the ordinary wet governor a lighter weight will give less pressure, and *vice versâ.*

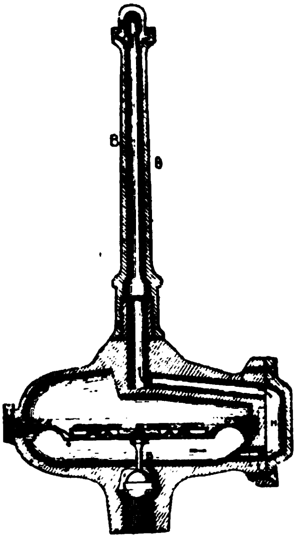


Fig. 139.

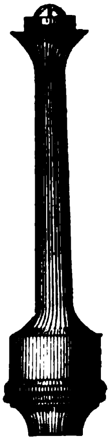
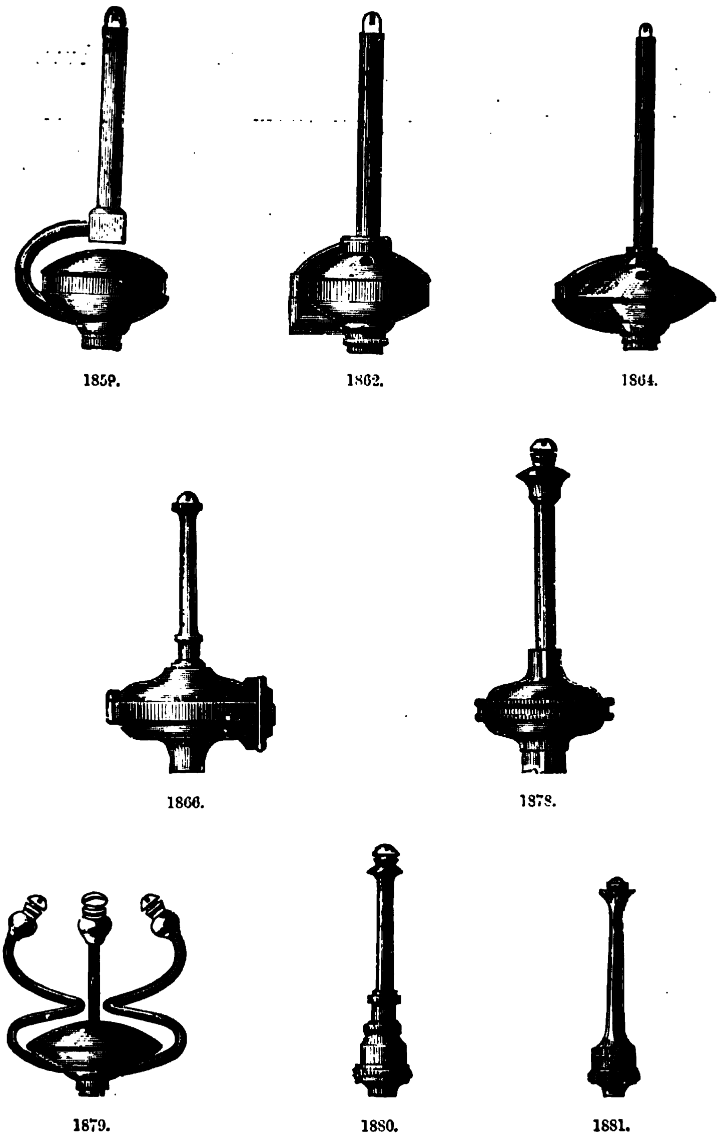


Fig. 140.

(N) is a hole communicating with the external air for the purpose of allowing the leather to rise and fall. If this hole becomes stopped, the governor will cease to act. The leather being sound, no escape of gas can take place when the governor is in operation.



1859. 1862. 1864.

1866. 1878.

1879. 1880. 1881.

Fig. 141.—Lamp Governors arranged Chronologically

Drawn to scale of one-quarter.

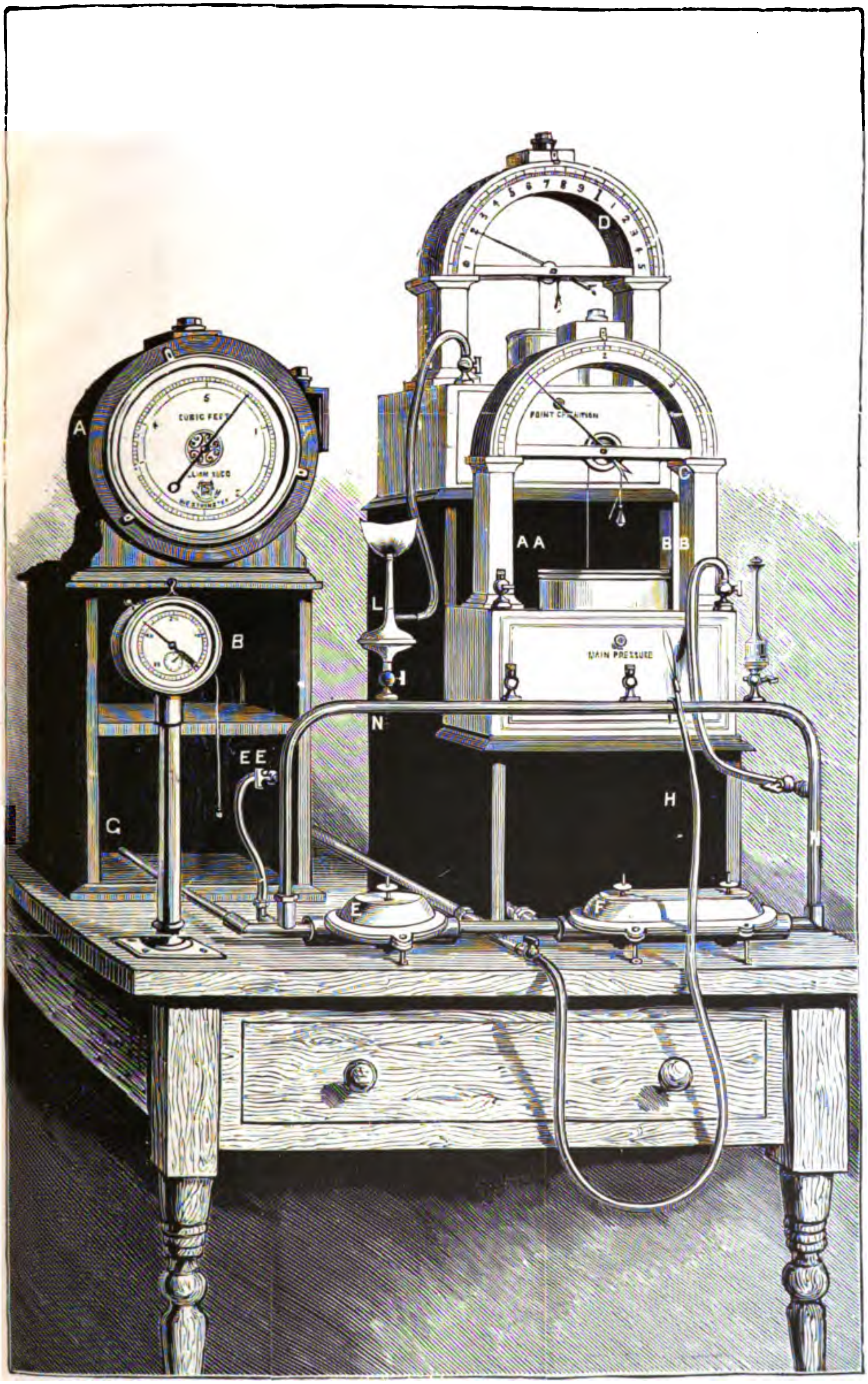


PLATE III.

To face page 273.]

The Steatite Float Lamp Governor (Fig. 140) has been introduced to meet the requirements of modern times, and is capable of working under more stringent conditions than were usual at the time the first governors were invented. It comes into action at the ordinary day pressure, and ensures a constant rate of consumption under pressures varying from $\frac{8}{10}$ to 6in. It differs from Fig. 139 by reason of the leather diaphragm being replaced by a steatite float, which, on rising by the increased pressure of the gas, reduces the free way of the outlet, and therefore works without the aid of mercury, glycerine, or other fluid.

The interesting series of woodcuts (Fig. 141) illustrate the development in the forms of lamp governors since 1859.

Messrs. Sugg and Co.'s Apparatus for Testing Lamp Governors (Plate III.)—The requisites for this purpose are:—

An experimental meter (A), with a measuring drum holding $\frac{1}{12}$ of a cubic foot, thus indicating at one revolution per minute a rate of 5 cubic feet per hour. The dial is divided accordingly, each foot being sub-divided into tenths of a foot.

A minute clock (B) striking each minute and fitted with stop action.

A King's pressure gauge (C) capable of showing 4in. of pressure.

Another (D), capable of showing $1\frac{1}{2}$in. of pressure, with sub-divisions into hundredths of an inch.

A single dry governor (E).

A double dry governor (F).

A float (N N) fitted with lamp cocks and stop-cock (E E) for high-pressure gas supply.

A brass T-piece (L) screwed $\frac{3}{8}$in. inside at the bottom, and $\frac{3}{8}$in. outside at the top, so that it may be inserted between the cone and the case of a governor which it is required to test in the readiest manner without disturbing the joints.

This T-piece is connected by means of an india-rubber tube to the delicate King's pressure gauge (D), which indicates the pressure of the gas after passing the governor. This pressure is considered to be that which would be found just inside the orifice of the burner, and is spoken of as the pressure at the point of ignition.

> **Note.—In the case of the steatite float lamp governors (page 271), in which the cone is in one piece with the case of the governor, the burner must be removed, and the T-piece must be screwed to the top of the cone.**

A flash-light (H) for lighting the burners, and connected by a long india-rubber tube with the ordinary gas service, so that it is not in communication with any part of the apparatus.

Action of the Apparatus.—The mode of action of the apparatus is as follows:—The high-pressure gas enters by the supply pipe (G), and passes through the governor (E) to the meter (A). Thence it returns and passes through the double governor (F) to the pipe (N N) called the float. This pipe is provided with stop-cocks, to which the governors or burners under examination can be attached, and is in communication at the one vertical portion with the gauge (C), and at the other with the high-pressure gas supply through the stop-cock (E E).

Fixing.—The best method of fixing this apparatus is that shown in Plate III.

The inlet (G) of the apparatus should be connected to the outlet-pipe of the gasholder (Fig. 142).

Although lamp governors are made for the purpose of maintaining by their action uniformity at the burner under varying pressures in the street mains, yet they themselves cannot be well adjusted unless there is a possibility of working with a standard pressure which can be relied upon to remain unchanged during the whole process of adjustment.

At the same time it is necessary, in order to prove the delicacy of the governor, to have a means of increasing the pressure at its inlet by degrees till the highest pressure is reached, when this is shut off, and the standard pressure resumes its influence.

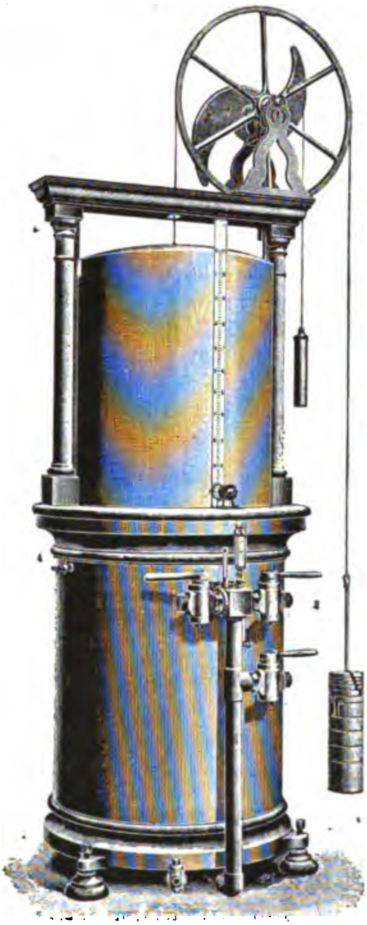


Fig. 142.

To maintain this standard pressure is the province of the double governor (F), fixed on the right of the meter, while that on the left (E) serves to regulate the degree of variation in the pressure which it is intended to cause at the inlet of the lamp governor under examination.

Adjustment.—Having arranged the apparatus in the order pointed out, see that the pointers of the pressure gauges are at zero when the gas is turned off.

Note.—For this purpose open the blow-off cocks (A A), and shut the gas cocks (B B).

Adjust the (F) or standard pressure governor till it gives a pressure upon the (C) pressure gauge equal to the lowest or day pressure in the mains (say 6-10ths).

Note.—In adjusting this governor (which is double), the inlet holder must be weighted to give about 2 or 3-10ths more than the outlet holder; thus, supposing the operator were adjusting the low-pressure governor (F) to give 6-10ths pressure, he would adjust the inlet holder to 8-10ths and the outlet holder to 6-10ths. This is done to allow for any variation of pressure which may occur at the outlet of the first holder, and in order that the second may be enabled to maintain at its outlet a perfectly uniform pressure.

Weight the test or store gasholder (Fig. 142) (if it is not possible to obtain the pressure from a large gasholder, or in any other way), up to 2in. or 2½in.

For all the purposes of testing, excepting for soundness, a pressure of 2in. is amply sufficient. To increase the pressure gradually from $\frac{6}{10}$in. to 1½in. is a severer test for a governor than suddenly to change it from $\frac{6}{10}$in. to 6in.

After adjustment of the high-pressure governor (E) to 2in., or nearly the pressure of the test gasholder, the apparatus will be in order for testing.

Supposing it is required to test a governor taken from, or ready to be fixed in a lamp, screw it on one of the cocks as at (L), commence by turning on the high-pressure cock (E E), and light the burner.

Note.—This is done in the case of the old pattern governors to put the governor in action in case it may have lain by for some time, and have become stiffened by reason of the oil from the gas being viscid. If put in action for a short time, the gas will itself restore the leather to its former condition.

Turn off the high-pressure cock and let the flame burn for at least one minute, then, when the hand of the meter is at 5, start the minute clock (which should be at zero), and at the moment when the bell strikes one minute, notice the position of the hand of the meter. The distance travelled over by that hand in one minute equals the rate per hour at which the gas is consumed by the burner; thus, if the hand has made the complete circuit of the dial, the consumption of gas is 5 cubic feet per hour; if from zero to 1, 1 foot per hour, and so on.

If it be necessary to ascertain whether the governor under examination varies under different pressures, then unscrew the cone and insert the T-piece (L), connecting the outlet of the T to the point of ignition gauge (D).

Commence with the low or standard pressure, and ascertain the rate per hour, after which turn on the high-pressure cock (E E) so as to gradually increase the pressure until the gauge shows that the highest point desired is attained.

> **NOTE.—The weight must be put on the outlet holder; after the first adjustment the inlet holder must not be touched, unless it is desired to increase or diminish the standard maximum pressure.**

By counting the number of hundredths of an inch of variation shown by the pressure gauge, that of the governor may be accurately ascertained; and by observing how much the consumption is increased, a table of variations for that particular size of burner may be readily made.

To ensure success in lighting street lamps upon the governor system, the burner and governor must be considered as one, and any accident which happens to either ought to be followed by the removal of both for re-adjustment.

It is desirable that all governors should be brought in for testing and cleaning at least once in three years.

Average Meter System.—The following description of the method adopted in the town of Nottingham for effecting the supply of gas to the public lamps on the system of average meter indication was submitted to the British Association of Gas Managers by Mr. Chas. Hawkesley in June, 1868, and is of special value as showing the manner in which the "meter system" was introduced.

Average meter indication appears to have been in use in one or two of the smaller towns in this country for a considerable period of years, but was first brought prominently into public notice when applied in conjunction with the "double tap" in the town of Reading during the year 1863, under the direction of Mr. Samuel Hughes.

The attention of the Nottingham Gas Company was, in the year 1860, called to the excessive quantity of gas consumed by the public lamps, and on investigation it was found that the mean average consumption by each lamp amounted, during the six months ended September 1st, 1860, to no less than 7·3 cubic feet per hour, although the contract with the town authorities provided only for 5 cubic feet per hour per lamp; and during a portion of the period referred to—viz., from the 1st to the 22nd of June—the consumption per lamp was found to have attained the enormous quantity of 9·5 cubic feet per hour. The amount of gas actually consumed (as ascertained by meters attached to several of the lamps), when divided by the number of hours during which the lamps ought to have been lighted according to the lighting table, gave the results mentioned above, showing great negligence on the part of the lamp-lighters, who, especially during the height of summer, lighted the lamps earlier and extinguished them much later than the hours stated in the table.

It was to amend the then unsatisfactory state of the arrangements with the lighting authorities of the town that the Company applied to Parliament, in the session of 1864, for an Act having amongst other objects the making of better and more effectual provisions with regard to the lighting of public lamps.

The Bill was opposed by the Corporation and the lighting authorities of the town, and after a severe contest before a Select Committee of the House of Commons, during which certain alterations were made in the Bill affecting the regulation of the public lamps, the Act was passed with the following clauses:—

"(15) Subject to the provisions of this Act the Company shall, at their own expense, upon the request in writing of any lighting authority, provide, lay down, fix, maintain, and keep in repair all mains necessary for the proper lighting of such of the streets within the said limits as are mentioned in such request, and provided the lamps to be supplied shall be fixed at not exceeding the average distance of 80 yards along the course of any main to be laid down by the Company for conveying gas to such lamps.

"(16) The Company shall, from time to time, at the request in writing of any such lighting authority, supply all or any of the present public lamps within the said limits, or such other public lamps to be hereafter provided and fixed as aforesaid, with so much gas, and to be delivered at and for such times and periods as the parties on whose request the supply of gas is made may from time to time desire.

"(17) The price to be charged by the Company, and to be paid to them by the lighting authority, within the extended limits by this Act authorised, for all gas so supplied to or for any such public lamps, shall always be calculated and fixed at and according to the lowest price for the time being charged by the Company to any private consumer in the parish or place within such extended limits in which such public lamps shall be situated.

"(18) The gas supplied to the public lamps within the limits of this Act and the recited Acts shall be consumed by meter, at the option from time to time of the lighting authority or the Company; and in case of its being consumed by meter, the meters shall be provided by the Company at the expense of the lighting authority, but neither party shall, except as hereinafter provided, be entitled to require that a meter be affixed to more than one in every twelve lamps then supplied with gas under this Act or the recited Acts; provided also that the Company shall be at liberty, if they think fit, to have a meter affixed to any additional number of lamps, they providing such meters, and paying to the lighting authority the additional expense of providing and adjusting lamps, lamp-posts, and other things necessary for their reception and use; provided always, that if the gas shall, under the provisions of this Act, be supplied to the public lamps by average meter indication, the Company shall, for securing uniformity of consumption between the metered and the unmetered lamps, from time to time provide the public lamps under the control of the lighting authority with proper regulating apparatus and burners to the satisfaction of the lighting authority, or, in case of difference, as from time to time shall be settled by the Justices in Petty Sessions assembled.

"(19) The average amount of the indications of all the meters attached to the public lamps under the control of any lighting authority shall be deemed to be the amount consumed by each such lamp.

"(20) The gas supplied to any such public lamp shall be permitted to pass unrestricted to and from such regulating apparatus for the whole of the period during which any such public lamp shall be lighted."

Subsequently, Mr. Hawksley, the engineer to the gas company, was instructed to take the necessary steps for the introduction into the town of Nottingham of the system of average meter indication, and with the assistance of Mr. William Sugg, he devised the modified form of meter and the burner cock now in use, with the view to overcome some of the difficulties which had previously been encountered where that system had been tried. The lamps at Nottingham were first lighted on the system of average meter indication in the beginning of the year 1866, since which, and up to the present time, that method of lighting has been maintained in operation without interruption. The apparatus employed is as follows:—

(1) Every lamp throughout the town is furnished with a brass cock, above which are fixed a governor and steatite burner.

(2) One lamp in twelve has, in addition to the above, a wet meter placed underground, near the foot of the lamp column.

The meter is of the compensating class, and, in order to reduce the friction to a minimum, the drum is made of the same diameter (about 12in.) as that of an ordinary five-light meter, but is so diminished in width as to have the capacity of a three-light meter only; it makes eight revolutions for each cubic foot of gas measured, and requires to work it a pressure of only half a tenth of an inch when passing five cubic feet of gas per hour.

The waste-water box is so arranged as to be capable of being emptied by means of an exhausting syringe introduced through a plug-hole in the top of the meter case.

The index is placed horizontally on the top of the meter, so as to be visible on raising the cover of the cast iron box in which the meter is placed. The index at first employed was made of brass, and of the ordinary pattern; but great trouble being given by the meters ceasing to register, it was discovered that the condensation in the dial box due to changes of temperature, and probably in some measure also to the evaporation from the water in the meter, corroded the wheelwork to so great an extent as to cause the breakage of the teeth of the wheels, and consequently to permit the passage of the gas without registration. It was then determined to make the indexes with strong wheelwork of gun-metal, afterwards tinned to preserve it from corrosion; and a simplified arrangement of index, suggested by Mr. Henry T. Humphreys, was used, consisting of two large wheels, each about 4¼ in. in diameter. Both wheels are worked by the same pinion fixed on a vertical shaft, which is driven in the usual way by a worm on the drum shaft. One of the large wheels is provided with 202 teeth, and is attached to a revolving dial plate, the circumference of which has 100 divisions, each representing 1 cubic foot of gas, indicated by means of a fixed pointer. The other large wheel is furnished with 200 teeth, and has attached to it a hand also pointing to the before-mentioned divisions on the dial plate, each of which now represents 100 cubic feet; but the number of teeth in this wheel being two less than those on the wheel to which the dial plate is connected, the hand revolves 1 per cent. faster than the dial plate, and thus indicates every 100 cubic feet of gas consumed up to 10,000 cubic feet, beyond which it is unnecessary to record in meters of this class.

Method of Reading the Index.—The index is of the kind called differential. The index hand and dial both revolve; but, as a consequence of the hand being fixed to a wheel having 200 teeth and the dial to another having 202 teeth, both of which are driven by the same pinion, the hand gains on the dial two teeth every complete revolution of the latter, which occurs when 100 cubic feet of gas have passed through the meter. Thus it follows that each of the smallest divisions is equal to 100ft. by the indication of the central hand, and 1ft. by that of the fixed pointer.

When the former has made a complete revolution of the dial, 10,000 cubic feet of gas will have been passed through the meter.

As a further precaution against corrosion, the index box is filled with refined oil to the level of the under side of the dial plate, and with the index thus made and protected no further difficulty has been caused through the meters having ceased to register.

The freezing of the water during the winter has been effectually prevented by the introduction into each meter of a small quantity of methylated spirit. This was at first found to interfere with the proper action of the meter, and it was then discovered that the spirit as ordinarily sold is mixed by the Customs authories with gum to prevent its use for the purpose of defrauding the Excise. Unadulterated spirit was afterwards obtained, on a certificate being given to the authorities as to the use to which it was to be applied, and no further inconvenience has been experienced. Additional protection against frost is afforded by filling with felt the space between the two covers of the meter box.

> Note.—This has not been effectual in every case, in consequence of the felt becoming wet, and serving as a conductor. It has been found that the air space between the lids is quite sufficient during ordinary frosts.

The meter is placed in a cast iron box let into the ground near the foot of the lamp-post, so that the cast iron lid, which is hinged, is level with and forms part of the foot pavement; beneath this lid is a false cover of iron to afford additional protection to the meter, which cover may, if required, be tightly screwed down on to an india-rubber washer, thus forming a water-tight joint and keeping the interior of the box dry even when immersed in water Apertures are left in the back of the box, through which to pass the inlet and outlet pipes, and these are made water-tight by means of washers and back nuts.

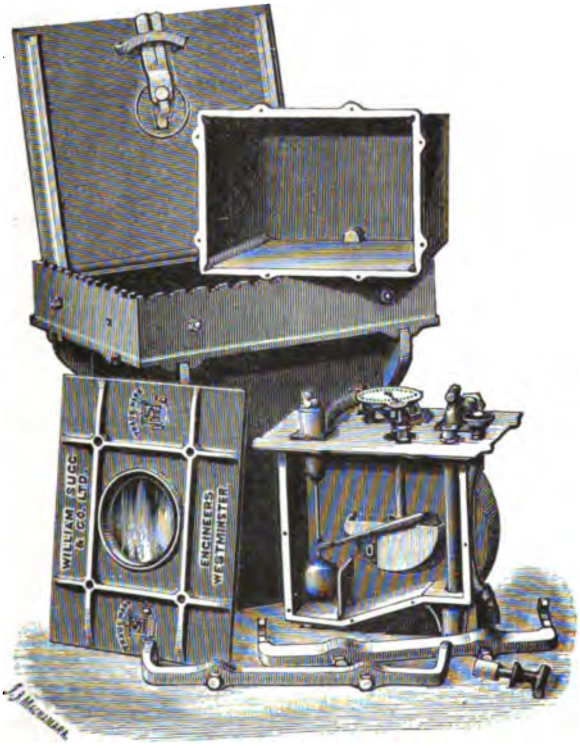


Fig. 143.

Mr. Sugg's public lamp meter consists of a cast iron box (Fig. 143), with roughed external lid, and with internal lid made tight with india-rubber, and fastened down by cotters and screws. The internal lid is fitted with glass, to enable the inspector to read the index without removal, and an improved double-latch lock, made to prevent dirt from falling through the keyhole into the meter.

The box is also fitted with inlet and outlet unions, fixed in a water-tight manner to the box, and an incorrodible metal service inlet, with plug for cleaning out stand-pipe. The external lid covers these arrangements, so that they are at any time accessible without breaking the ground or disturbing the pavement. The external lid and frame are adjustable, by means of four screws, to the pitch of the pavement in any direction.

The meter is provided with levelling screws and flexible joint with strong gun-metal union, and is provided with a new form of index, which is made of bronze, has no pinions, and only one large wheel. It can be rapidly read in any direction. It is provided with a compensator and water-line regulator. An independent back and front enables the working parts of the meter being lifted bodily out of the case for the purpose of repairing and for adjusting the bearings—which may be done by an unskilled mechanic rapidly and surely on the spot.

After having passed through the meter, the gas ascends by a pipe placed in the usual manner in the lamp column until it reaches a brass cock placed between the top of the post and the underside of the lantern. This cock is opened and closed by means of two short brass arms, curved downwards, so as to be readily caught by the end of the lighting torch. The plug is made longer than usual, for the purpose of securing tightness and resisting the blow of the lighting torch when used with rapidity, and the stops are so placed that the plug cannot make more than a quarter of a revolution. This arrangement ensures the opening of the cock to to the full extent whenever the lamp is lighted, without requiring care on the part of the lamp lighter, who has merely to push up the lever as far as it will travel, and who would, indeed, have some difficulty in opening the cock only partially, were he even disposed so to do.

immediately above the cock, but inside the lantern, is placed the governor, an instrument without which the system of average meter indication could never have been satisfactorily adopted.

Meters were attached in the case of Nottingham to one lamp in twelve, the lighting authorities having elected to have that proportion, although the gas company were willing to adopt one in twenty; it is, consequently, of the utmost importance that the governors and burners of any one series of twelve lamps should each be accurately adjusted to consume an equal quantity of gas, otherwise the metered lamp would cease to afford a correct indication of the consumption of the whole of the remaining eleven lamps. The governors, with their burners attached, are therefore, in the first instance, separately adjusted to a consumption of 5 cubic feet of gas per hour; they are then placed twelve in a row, and are again tested for an hour, when, if the total consumption during that time is found to be 60 cubic feet, they are issued for fixing to the lamps, the governor and burner for the metered lamp being taken indiscriminately from the set of twelve. Care is, however, taken to keep each set distinct, and in the event of any future readjustment or repair being required to the governor or burner of any one of the set, the remaining eleven are also removed from the lamps, and the whole are again tested together before being refixed. With these precautions no difficulty is experienced in maintaining uniformity of consumption in both the metered and the unmetered lamps.

It is of the greatest importance that the meters should be regularly tested—say, once in two years. By the use of a portable test meter, the inspection can be made with the meter *in situ*; but regard must be had to the temperature. Thus, in very cold weather, or when it is extremely hot, it is well to pass about 15ft. through before commencing a test.

Portable Standard Test Meter.—This meter (Fig. 144), which is especially constructed for portability, is used to test meters *in situ,* and thus avoid the inconvenience and expense connected with their removal to a testing office.

It is provided with stout levelling screws, two spirit levels, two pressure gauges, two water-level gauges, and a thermometer. For safety during removal the gauges and thermometer are disconnected, and the apertures are closed by caps, which are attached to the meter by small chains.

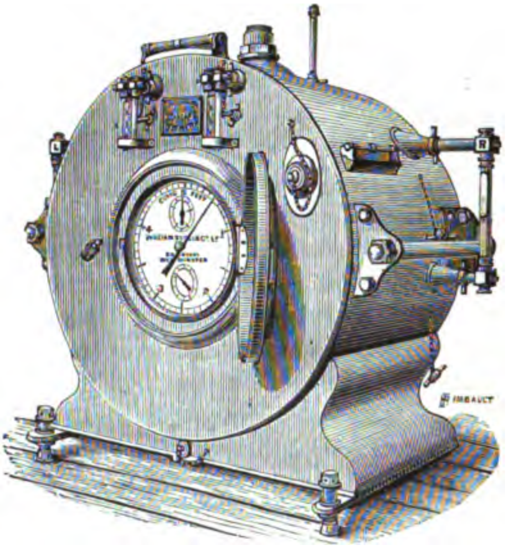


Fig. 144.

The glass in front of the dial is protected by a metal door, which can be secured by a padlock. The case is made extra strong, and is provided with two stout handles.

The results of the application of the average meter system in Nottingham may be summarised as follows, the figures given being confined to a period of eighteen months:—The indices of the meters were recorded monthly, and returns made both monthly and quarterly showing the situation of each metered lamp, the state of the index, the number of cubic feet of gas consumed during that period, the number of hours during which the lamp was alight, and the consumption per hour by each lamp.

The Table XLIV. shows the results of the eighteen months' working.

TABLE XLIV.

Table showing the Results of the System of Average Meter Indication as applied to the Public Lamps within the Town of Nottingham, during the Eighteen Months ended March 31st, 1868.

Number of Metered Lamp.	Situation.	Consumption in cubic feet per hour for the quarter year ended						Consumption in cubic feet per hour at each Lamp on average of 18 months.
		1866.	1867.				1868.	
		Dec. 31.	Mar. 30.	June 29.	Sept. 30.	Dec. 31.	Mar. 31.	
10	Newdegate-street	4·54	4·74	4·86	4·71	4·56	4·72	4·68
20	Park-row	4·15	4·37	4·49	4·55	4·47	5·00	4·50
30	Wilford-road	4·69	5·02	5·05	5·20	4·88	4·90	4·95
40	Canal-street	3·70	4·19	4·49	4·87	4·56	4·45	4·37
50	Robin Hood-street	4·23	4·46	4·68	5·20	4·64	4·63	4·64
60	Vicarage-street	4·23	4·56	4·86	4·87	4·88	4·63	4.67
70	Stoney-street	4·38	4·56	4·68	4·55	4·31	4·27	4·45
Average consumption per hour of the above 7 lamps during each quarter year		4·27	4·55	4·73	4·85	4·61	4·65	4·60
Average consumption per hour of the 72 metered lamps within the town of Nottingham during each quarter year		4·32	4·64	4·71	4·86	4·69	4·68	4·65
Maximum consumption per hour of any of the 72 metered lamps within the town of Nottingham during each quarter year... ...		4·85	5·3	5·24	5·36	5·29	5·27	—
Minimum consumption per hour of any of the 72 metered lamps within the town of Nottingham during each quarter year... ...		3·70	4·09	4·11	4·22	4·15	4·27	—

CHAPTER XVI.

TORCH LIGHTING AND EXTINGUISHING.

THIS system which, since its introduction into England a comparatively short time since, has been constantly increasing in favour, is, however, no new thing, for on the Continent it has been practised for a very long time.

However it may have succeeded there, it was nevertheless clearly unsuited to the system of lighting adopted in this country, until the application of governors and steatite burners to street lamps. With these improvements it is found to work uncommonly well, because a simple movement is all that is necessary to turn on the gas, which requires no adjustment, and if the lamplighter brushes his burners when he cleans the lamps, he may confidently depend upon the shape of the flame being always good. The turning off of the gas has for many years been done almost everywhere with the aid of a stick, and to this cause may be traced the almost universal loss of one or more of the bottom glasses which ought to be found in every street lantern.

A proper amount of ventilation is necessary, or the lanterns would soon fall to pieces from the heat generated by the combustion of what is, considering the size of the chamber in which it is consumed, a very large quantity of gas; but no one who sees the flames blowing about in the manner they do can reasonably say that the best way of ensuring that result is attained by the absence of the bottom of the lantern. It is very probable that the loss of gas and consequent loss of light caused by this strong draught would compensate in a very short time for the expense of putting in the bottoms and keeping them in proper repair. In Paris the gas company has become so strongly convinced of this fact that they have gone to a very considerable expense in fitting to the lanterns an arrangement of plate glass mounted upon a brass swivel fixed on the supply pipe, which is opened and closed by the lamplighter when he lights the lantern, the hole through which the supply enters the lantern being carefully stopped, if not by the arrangement just spoken of, then by putty.

The torch-lighting system requires but little explanation, and is as follows, viz.:—

The lamplighter is provided with a torch (Fig. 145), which is simply a small lamp in a brass case, the top part of which is drilled full of holes to admit air to the flame, but so guarded by an inner screen that the wind or a violent motion in carrying it about will not extinguish it, and mounted upon a light staff, varying in length, and jointed or not as may be required. With this he hits the lever of the cock (Fig. 146) on one side to turn it on, and the other to shut it off. There is a little hole at the top of the torch which projects a ray of light upon the lever sufficient to enable the lighter to find it upon a dark night.

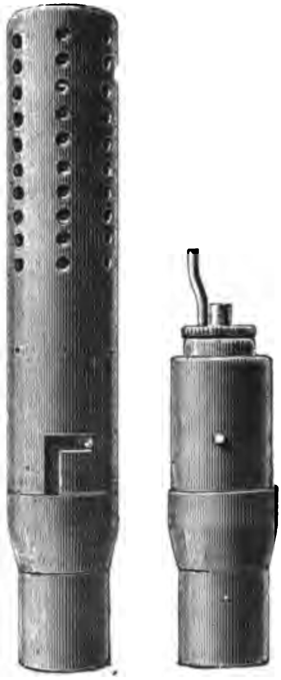


Fig. 145.

Note.—**On rainy nights the torch should not be carried perfectly upright, or a drop of rain falling into this small hole may extinguish the light.**

Immediately the cock is turned on the torch slips off the lever, and striking the glass flap, which is hung on a piece of brass tube soldered along the back of the frame of the lamp into which it fits, lifts it, and passing up ignites the gas immediately; the torch being withdrawn the flap falls of itself.

It is obvious that to ensure the success of the system, and prevent loss of gas, it is essential that the stops of the cocks should be sufficiently strong to withstand the continual blows of the torch.

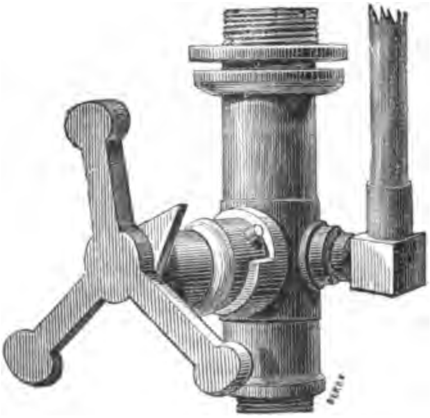


Fig. 146.

Lever Cocks for Large and Small Lamps.—These cocks are fitted with stout knobs at the ends of the levers, and with a pointer to indicate whether the gas is off or on.

Triple Lever Cock for Large Lamps (Fig. 146).—This was invented for the purpose of facilitating the lighting and extinguishing lamps in which it is required to reduce the consumption of gas after midnight.

When the full-power lighting is turned on the pointer (Fig. 146) is upright.

When the midnight supply is on the pointer is turned in the direction of the elbow carrying that supply pipe. When the pointer is turned in the opposite direction, it indicates that the gas is entirely shut off.

In the case of large lamps in which it is required to have a reduced consumption of gas after certain hours, and in addition to that a flash-light which is always burning, the arrangement represented in Fig. 147 has proved the most satisfactory. This enables the lamplighter to have the main ring, or cluster of flames, alight without the centre one.

Foulger Patent Torch (Fig. 148).—One of the most modern and satisfactory torches was introduced to meet the requirements of the incandescent system of street lighting. By its means flash-lights and flap-doors are abolished, thus effecting a considerable saving in the mantles.

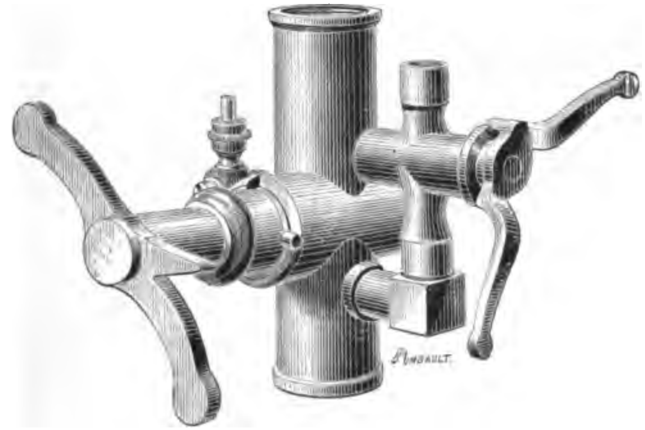


Fig. 147.

Fig. 148 shows a special lantern to be used with the torch, the essential feature of which is the ball-trapped door introduced by Mr. Sugg. The torch designed by Mr. Foulger, as it enters the door, pushes the ball to one side, and when the torch is withdrawn the ball returns down the inclined plane and closes the opening. The rod

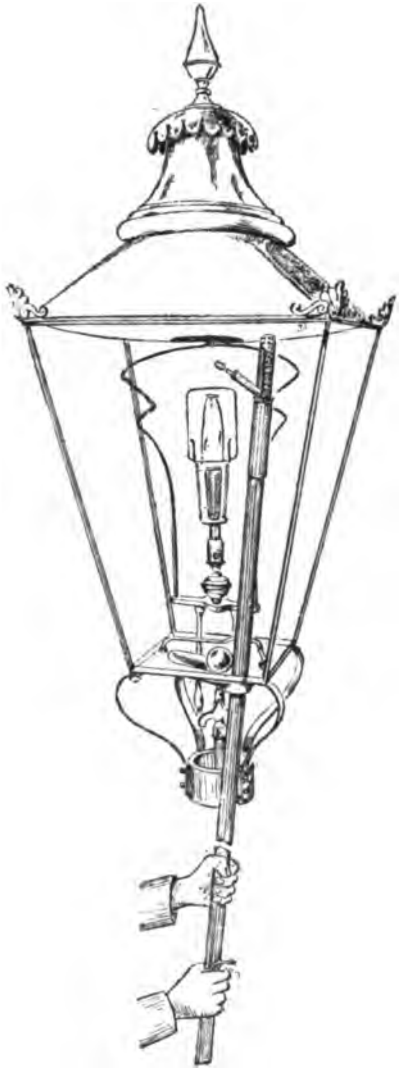


Fig. 148.

of the torch is fitted with a sliding device, which is gripped by the hand and pulled downwards when the gas is to be lit. This action releases the spirit lamp, which then inclines over the mantle and lights the gas.

The Simmance and Abady System of Lighting Incandescent Street Lamps.—This consists of two forms, one

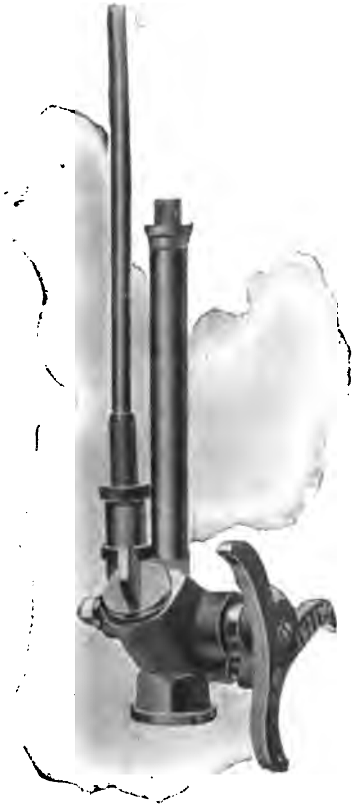


Fig. 149.

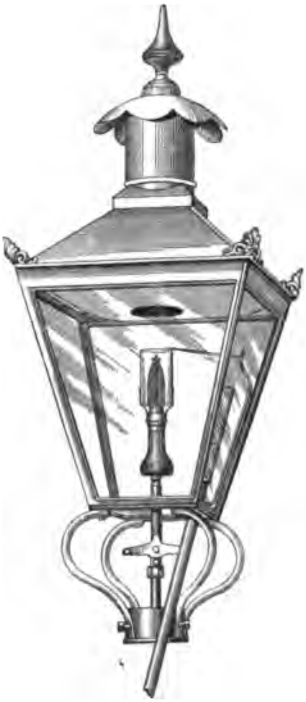


Fig. 150.

(Fig. 149) being a special triple-ported cock, with a short tube running up the corner of the lantern, and which tube is perforated for a jet. The ordinary lamplighter's torch is used to turn the cock half on, giving gas to both the jet tube and the incandescent burner The torch is inserted in the lantern and the jet lighted (Fig. 150), flashing across and lighting the burner. The cock is then turned full on, which extinguishes the jet, leaving the burner alight. The second form is a special torch (Fig. 151) which contains, besides the ordinary colza oil reservoir, a carburetter containing benzoline. The vapour of this latter is blown across the colza flame by a sudden pressure of the hand on the flexible cover of an air reservoir in the handle, and issues at the side of the torch as a pencil of ignited gas, some 6in. or 8in. in length. Thus the incandescent burner is lighted without approaching the torch within 8in. of the mantle (see Fig. 152), preventing

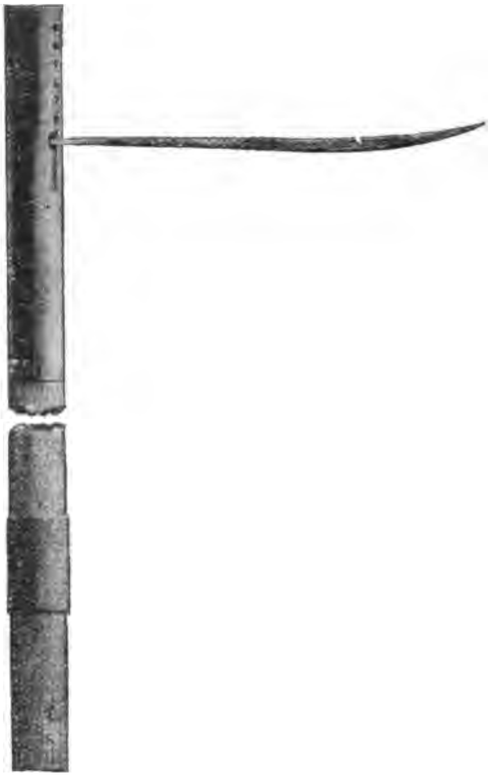


Fig. 151.

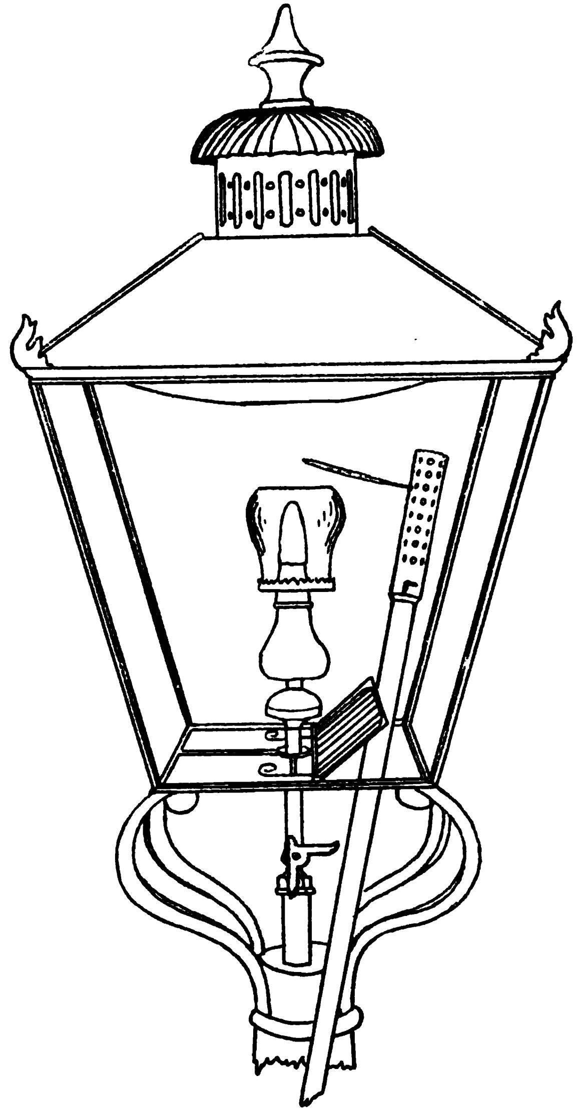


Fig. 152

the accidents which occur when torches are approached within an inch or so of the burner in the endeavour to light. This S. and A. torch is used largely in England, and most of the incandescent burners in Paris and Vienna streets are also lighted by the system.

CHAPTER XVII.

STREET LIGHTING TABLE.

In order to avoid disputes, it has always been necessary that the lamplighters should work according to a properly-constructed lighting table.

These tables are now mostly made up from the data given in the Nautical Almanack. As will be seen by an inspection of the various curves given, such tables can only be accurate for certain places.

By the use of Mr. Sugg's lighting diagrams, extended and rendered applicable to all parts of the world by Mr. Jas. T. Brown, accurate tables may be constructed for any part of the globe. The curves on the accompanying Diagrams F and G have been calculated from astronomical data. The horizontal lines are at intervals of one week, and the perpendicular lines represent the hours of the day and night. The curve which crosses and re-crosses the noon line shows the irregularity in the sun's time.

The following are the places to which the various curves refer:—

Curves.

No. 1. **Lat. 64° North.—**
Norway, N. of Christiana.
Sweden, N. of Stockholm.
Russia, N. of St Petersburg

No. 2. **Lat. 58° North.—**
Scotland.
England, N. of York.
Ireland, N. of Belfast.
Russia, S. of St. Petersburg.
Russia, N. of Warsaw.
Denmark.
Norway, S. of Christiania.
Sweden, S. of Stockholm.

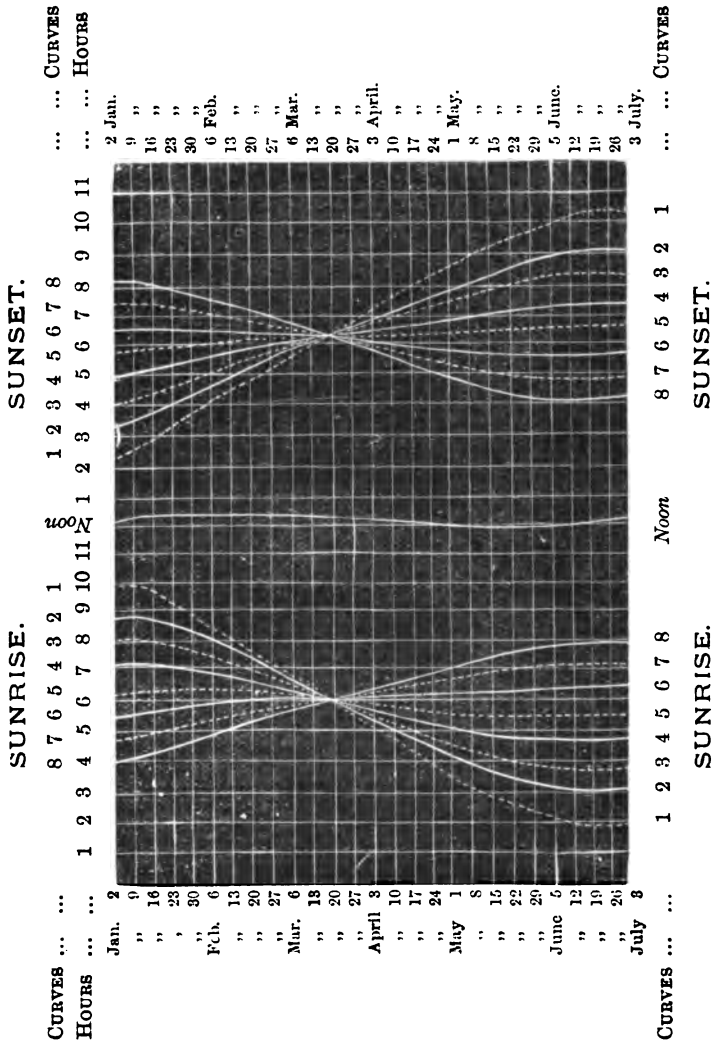

SUNRISE.
SUNSET.
Curves 8 7 6 5 4 3 2 1
Curves 1 2 3 4 5 6 7 8
Hours ... ... 1 2 3 4 5 6 7 8 9 10 11 Noon 1 2 3 4 5 6 7 8 9 10 11
Jan. 2
" 9
" 16
" 23
" 30
Feb. 6
" 13
" 20
" 27
Mar. 6
" 13
" 20
" 27
April 3
" 10
" 17
" 24
May 1
" 8
" 15
" 22
" 29
June 5
" 12
" 19
" 26
July 3
Noon

Diagram F.

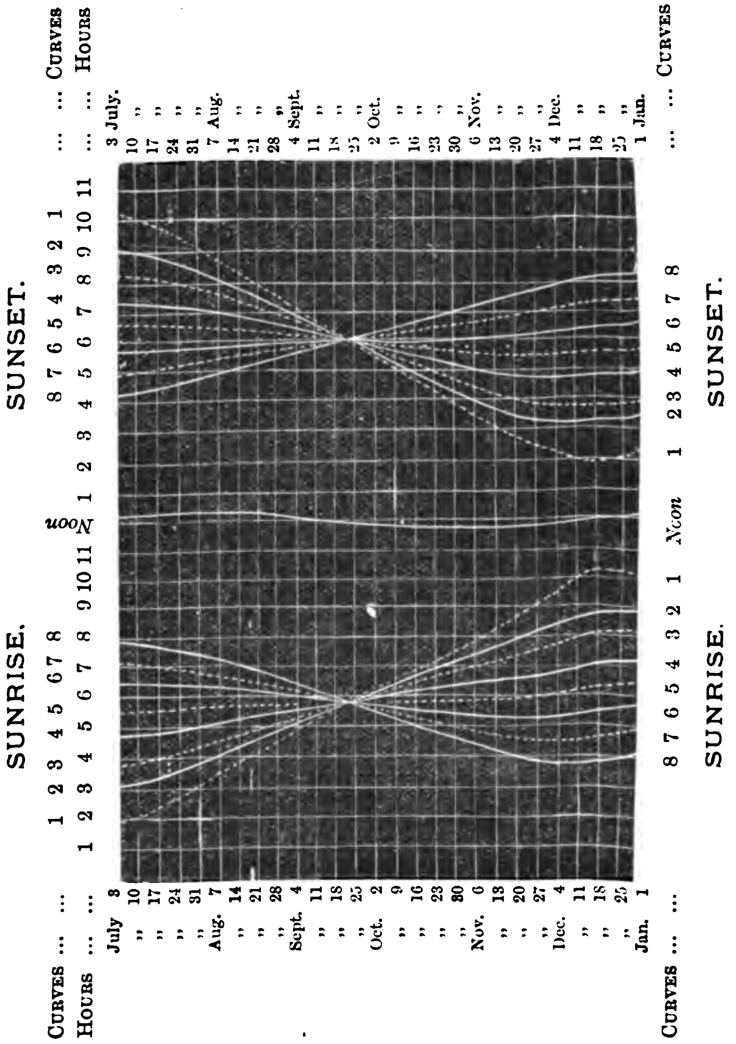

SUNSET.
SUNRISE.
Curves ... ...
Hours ... ...
1 2 3 4 5 6 7 8
1 2 3 4 5 6 7 8 9 10 11 Noon 1 2 3 4 5 6 7 8 9 10 11
Noon
3 July. 10 17 24 31 7 Aug. 14 21 28 4 Sept. 11 18 25 2 Oct. 9 16 23 30 6 Nov. 13 20 27 4 Dec. 11 18 25 1 Jan.

DIAGRAM G.

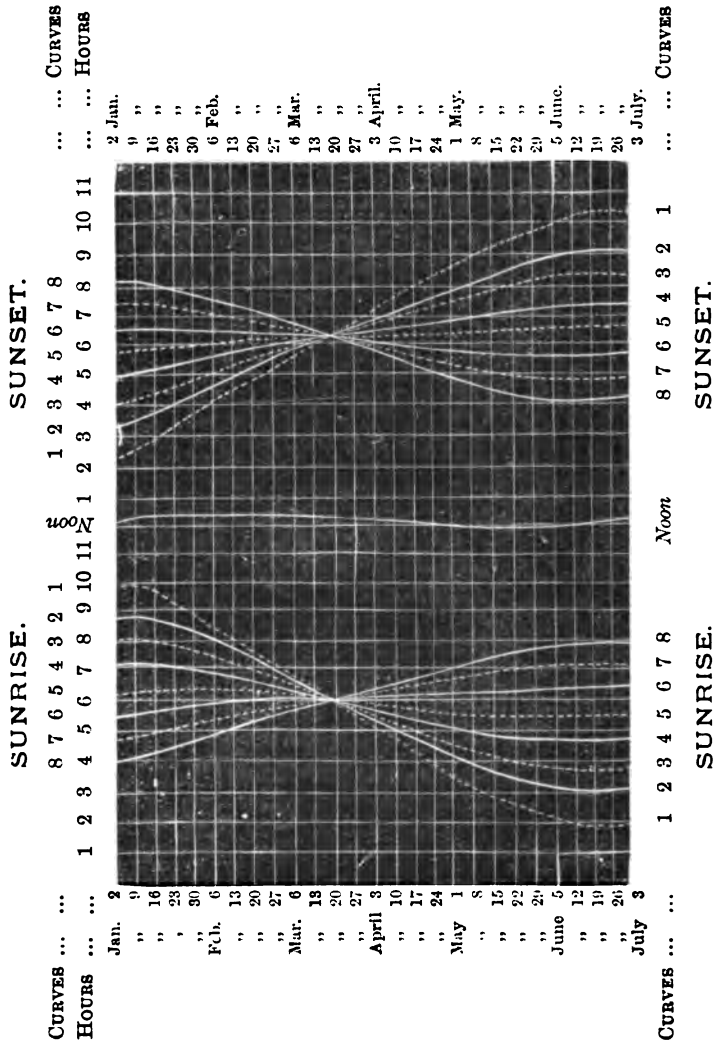

SUNRISE.
SUNSET.
Curves 8 7 6 5 4 3 2 1
Hours ... ... 1 2 3 4 5 6 7 8 9 10 11 Noon 1 2 3 4 5 6 7 8 9 10 11
Curves 1 2 3 4 5 6 7 8
Curves 1 2 3 4 5 6 7 8
Noon
Curves 8 7 6 5 4 3 2 1
Jan. 2
" 9
" 16
" 23
" 30
Feb. 6
" 13
" 20
" 27
Mar. 6
" 13
" 20
" 27
April 3
" 10
" 17
" 24
May 1
" 8
" 15
" 22
" 29
June 5
" 12
" 19
" 26
July 3

DIAGRAM F.

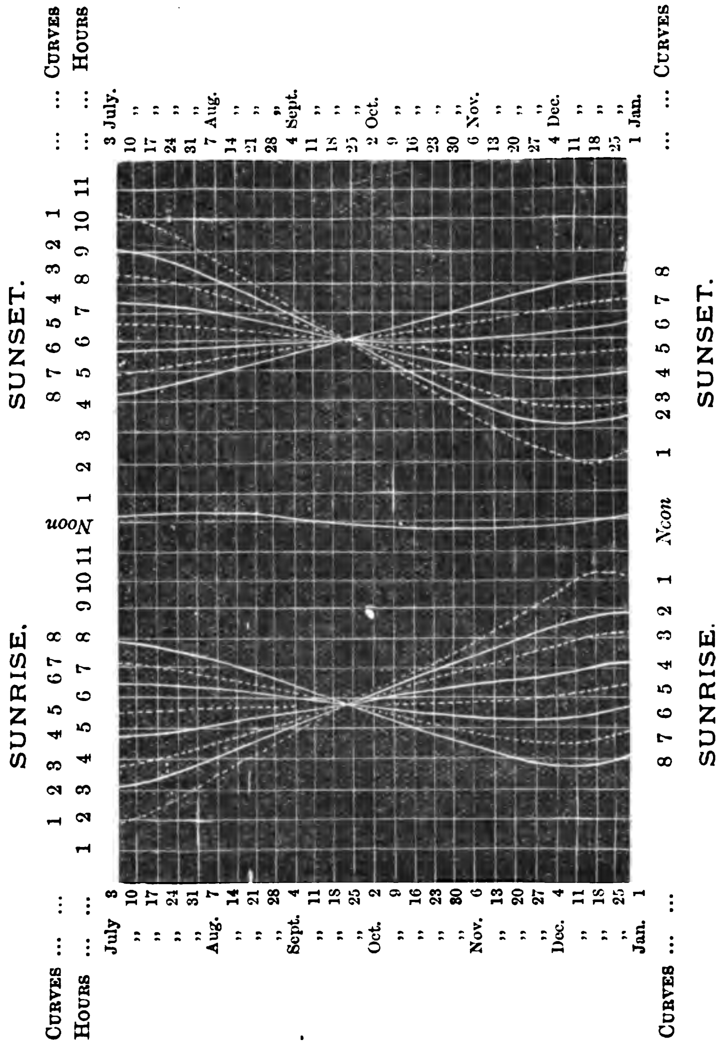

SUNRISE.
SUNSET.
Curves ... ...
Hours ... ...
1 2 3 4 5 6 7 8
8 7 6 5 4 3 2 1
1 2 3 4 5 6 7 8 9 10 11 Noon 1 2 3 4 5 6 7 8 9 10 11
July 3
10
17
24
31
Aug. 7
14
21
28
Sept. 4
11
18
25
Oct. 2
9
16
23
30
Nov. 6
13
20
27
Dec. 4
11
18
25
Jan. 1
Curves ... ...
8 7 6 5 4 3 2 1
Noon
1 2 3 4 5 6 7 8
SUNRISE.
SUNSET.

DIAGRAM G.

CURVES.

No. 3. Latitude of London.—
England, S. of York.
Ireland, S. of Belfast.
Russia, S. of Warsaw.
France, N. of Bordeaux.
Belgium.
Holland.
Switzerland.
Canada.
United States, N. of Oregon.
Austria.
Germany.
Prussia.

No. 4. Lat. 35° North.—
Spain.
France, S. of Bordeaux.
Portugal.
Italy, S. of Turin.
Turkey.
Turkey in Asia.
Persia.
Egypt.
Algeria.
United States, S. of Oregon.
Greece.
India, N. of Allahabad.
China.
Japan.

No. 5. Lat. 14° North.—
India, S. of Allahabad.
Africa
  N. of Equator.
  S. of Egypt.
South America, N. of the Equator.
Canton.

—Equator—

No. 6. Lat. 14° South.—
Northern Australia.
Africa
  S. of the Equator.
  N. of Cape Colony.
S. America
  N. of Rio Janeiro.
  S. of the Equator.

No. 7. Lat. 35° South.—
Southern Australia.
Cape Colony.
S. America
  S. of Rio Janeiro.
  N. of C. Corriento.

No. 8. Lat. 49° South.—
Cape Horn.
Tasmania.
New Zealand.

In order to impress more firmly the fact that, while countries north of the equator are having long days, those south of the equator are having long nights, the table may be divided into two portions at midsummer. The numbers at the bottom of the curves will then show that their relative positions are reversed.

In the arrangement on the diagrams the spaces between the curves of the same title indicate the length of the day in various parts of the world, as enumerated. The reversed order points out to the gas engineer the number of hours of darkness under various circumstances of time and place, and enables him to construct, on an accurate basis, a lighting table suitable to the requirements of the locality.

Roughly speaking, the hours between sunset and sunrise amount in the course of a year to 4300, and some vestries make their contracts for public lamps on this basis. The majority, however, take advantage of the twilight and dawn, especially during May, June, and July, and by lighting later and extinguishing earlier, they reduce the number of hours to 3940. Some reduce the number of hours of lighting to 3836, while some even adopt the rule of lighting half-an-hour after sunset and extinguishing one hour before sunrise, thus bringing the total down to 3760.

In country districts the moon is often taken into consideration. In those parts the instructions are that the lamps are to be lighted one hour before the moon sets and extinguished one hour after the moon rises. This rule only gives about 2300 hours of lamplight.

The following table gives the monthly totals of lamplight for the yearly totals of 4300, 3940, and 3836 hours at all places mentioned under curve 3.

TABLE XLV.

	H. M.	H. M.	H. M.
January	484·2	466·0	457·13
February	397·45	378·16	370·16
March	375·35	346·59	338·12
April	303·54	269·5	260·35
May	260·23	211·23	202·36
June	224·31	174·55	166·25
July	246·18	199·15	190·28
August	294·1	254·58	246·11
September	341·54	310·53	302·23
October	414·41	397·14	388·27
November	454·57	444·32	436·20
December	501·59	486·30	477·36
	4300·0	3940·0	3836·24

But the distribution of those hours over the month is a matter of considerable importance if it is desired to avoid the absolute waste of gas which must result from the use of defective lighting tables, not constructed on proper astronomical data.

CHAPTER XVIII.

EFFECTS OF IMPROVED METHODS OF LIGHTING BY GAS.

Saving Effected by Improved Methods of Illumination.—It is exceedingly difficult to obtain reliable statements as to the effect of improved systems of artificial illumination in consequence of the many factors entering into the question. It is therefore with peculiar pleasure that the writer is able to point to the following extracts from the official report of the Asylums Committee of the London County Council, in which the excellent engineer of the Committee, Mr. Wm. Chas. Clifford Smith, M.I.C.E., reports the results of alterations carried out by him on the lines of previous reports made by the writer in his former official capacity.

Extract from " The Tenth Annual Report of the Asylums Committee and the Sub-committees of Banstead, Cane Hill, Claybury, Colney Hatch, Hanwell, the Heath (Bexley), and Horton Asylums." London County Council, No. 441. 1899.

Page 55 :—Portion of " Asylums Engineer's Report to the Sub-committee of Cane Hill Asylum, April, 1899."

" *Gas Consumption.*—A small addition to the number of incandescent burners has been made in the year, there being 910 now in use, against 832 when I last reported. While the lighting gives full satisfaction, the gas bill continues to decrease. The following return shows very clearly how the extended use of the special burners has affected the consumption of gas:—

Four quarters ended—	Gas consumed. Cubic feet.
Lady-day, 1895, ordinary burners, and 6 incandescent burners in use	13,105,090
Lady-day, 1896, ordinary burners, and 450 incandescent burners in use	12,247,070
Lady-day, 1897, ordinary burners, and 742 incandescent burners in use	10,656,000
Lady-day, 1898, ordinary burners, and 832 incandescent burners in use	10,330,710
Lady-day, 1899, ordinary burners, and 910 incandescent burners in use	9,457,920

It is to be borne in mind when comparing the returns that the incandescent burner displaces at least one ordinary burner and frequently several, but in every case an improvement in the lighting is obtained. This was and is the sole object of the change. The total saving effected by the decrease in gas consumed for the period under review, in comparison with the expenditure for gas in 1894-5, is as follows:—

	£	s.	d.	£	s.	d.
3,647,170 cubic feet gas (decreased consumption)				413	6	5
Account for burners, mantles, rods, chimneys, &c.	176	11	9			
Wages of fitter, 52 weeks at 36s., engaged in attending to lighting	93	12	6	270	4	3
Clear saving				£143	2	2

The effect of improved methods of street lighting by means of the Welsbach system is well illustrated by the following two most valuable reports made by Mr. C. R. Bellamy, Assoc. M. Inst. C.E., the able City Lighting Engineer of Liverpool. Reporting on the 23rd July, 1897, Mr. Bellamy stated that:—

> The incandescent gas burner (Welsbach patent) came into practical use in 1893, and was first adopted in Liverpool for street lighting purposes in May, 1894. The advantage offered by this form of burner

was a much higher light efficiency, developing in Liverpool a maximum of 20 candles per foot of gas, as compared with four candles with the best type of ordinary flat-flame burner. For comparative purposes it is necessary to base calculations on a much lower efficiency, as in practice it is found that there is a continuous depreciation of the mantle during use. A large number of tests of new mantles, and those that have been in use for varying periods between one and nine months, show that an average efficiency of 18 candles throughout the useful life of the mantle may be assumed.

On this calculation the incandescent gas burner is shown to yield more than three times the light of the ordinary flat-flame burner consuming the same amount of gas. The first experiment on a large scale in Liverpool was carried out in Lime-street, where 154 burners were fixed in the then existing high-power lamps, in clusters of two or three, in place of flat-flame burners. The gas consumption under the flat-flame system was exceedingly high, amounting to 4,291,819ft. per annum, which was at once reduced by the adoption of the incandescent gas burner to 940,041ft., effecting a saving in the gas charge of £502 13s. 10d. per annum.

The disadvantages attending the use of the incandescent gas burner were principally the difficulty in lighting the burner surrounded by a glass chimney, and the fragility of the mantle, rendering frequent replacements necessary. Owing to the unsuitable construction of the Lime-street lamps it was found, as the result of a year's working, that each burner required on an average the following renewals, viz.:—

Mantles	13
Chimneys	12
Mantle rods	3

amounting in the aggregate, under the then existing prices, to an annual maintenance charge (including a labour item of 1s. 5d.) of 20s. 3d. per burner.

At that time the most approved method of lighting was by means of a small by-pass or pilot light, provided within the mantle, which remained lighted during the day, for the purpose of igniting the main supply when turned on by the lamplighter at lighting time. It was found, however, in practice, that these pilot lights were unreliable, a proportion of them becoming extinguished during the day, necessitating a special visit of the lamplighter with a ladder after completing the lighting of his district. Added to this was the deterioration of the mantle due to its use, and the cost of the maintenance of the pilot light, the consumption of gas for the purpose being assessed at ·25ft. per hour, which amounted to an annual consumption of 1428 cubic feet, involving an addition to the ordinary lighting charge (with gas at 3s. per 1000) of 4s. 3d. per burner per annum.

It was therefore found that, under the closest supervision, the renewals and the additional gas for the pilot light involved an aggregate annual charge of £1 4s. 6d. per burner in excess of the ordinary gas burner, which was regarded as unsatisfactory.

Efforts were made to reduce this charge by abolishing the pilot light and lighting the burner by means of a match and ladder. This was found both costly and inconvenient to the public, and further efforts were made to obtain a lamp in which the burner should be used under the best conditions in respect of ventilation, suitability of position, freedom from vibration, and capable of being lighted by the lamplighter in the same way as the ordinary lamp, viz., by means of a torch and pole.

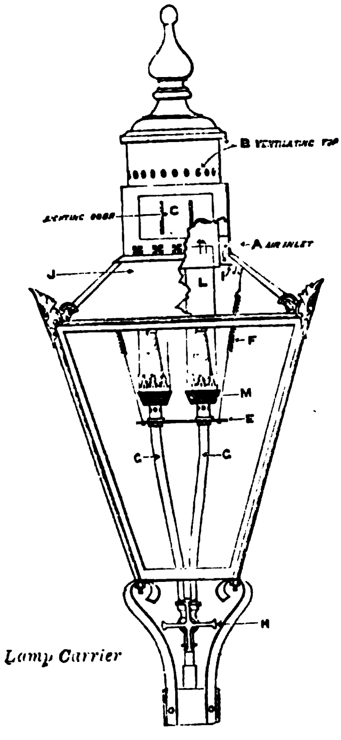


Fig. 153.

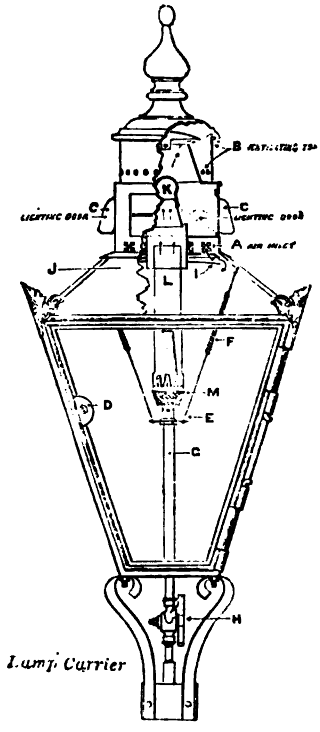


Fig. 154.

This resulted in the production of the lamp at present in use, which is shown on the accompanying drawings, where:—A (Figs. 153 to 155) is the air inlet. B the ventilating top. C the lighting doors, two being provided, fixed in line with the street, to enable the lamplighter to use the door on the side of the lamp opposite to the direction of the wind, the lamp being lighted by thrusting the torch through the lighting door into the box marked K, where the gas, escaping through the chimney L, is lighted. D, cleaning door with lock.

As all the products of combustion are carried by means of the chimneys into the lighting box beyond the glazed portion of the lantern, internal cleaning is necessary only at long intervals. Frequent access is therefore not required, and the locking of the door prevents interference with the burners. E, suspension platform. F, suspension wires and springs.

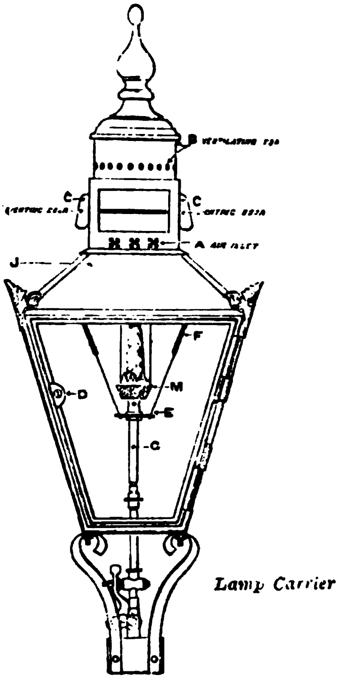


Fig. 155.

The springs permit of the platform being depressed, which draws the glass chimney out of the copper chimney and permits of the renewal of the parts without disconnecting the platform E. G, flexible tubes. H, three-way cock, for double-burner lamp. This is so arranged that either or both of the burners may be used, the practice being to light both until midnight, and, with weekly alternations, one of the burners remaining lighted until daybreak. I, enamelled steel reflector, acting as a baffle plate to the fresh air supply. J, opal glass reflectors. M, wire gauze cup to prevent back lighting.

It has been stated at various times that the lighting of a burner over the chimney is detrimental to the mantle, but it has been found in Liverpool to be a distinctly beneficial process, as it does away with a continuous passage of air, laden with the products of combustion arising from a luminous flame, and the dust of the atmosphere, due to the use of the by-pass jet within the mantle during the hours of daylight, and, as a subsequent table shows that a number of mantles have been in use under this system for nine months, or 2341 hours, with an average efficiency at the end of this time of 10·39 candles per foot of gas, it must be admitted that this system of lighting is beneficial to the mantle, and is the most satisfactory yet adopted.

TABLE XLVI.

Illuminating Power Tests of Incandescent Gas Mantles Removed from District.

Date of fixing.	Date of test.	Months in use.	Lamp hours.		Candle-power.*
			hr.	min.	
9th Oct., 1896	15th July, 1897	9	2378	57	34·03
,,	16th July, 1897	9	2383	37	30·05
,,	,,	9	2383	37	25·18
14th Oct., 1896	15th July, 1897	9	2331	31	27·54
,,	,,	9	2331	34	41·02
,,	,,	9	2331	34	28·47
,,	,,	9	2331	34	39·07
,,	,,	9	2331	34	27·56
15th Oct., 1896	,,	9	2322	6	32·59
16th Oct , 1893	,,	9	2312	37	30·46
,,	,,	9	2312	37	27·17
29th Oct., 1896	7th July, 1897	8	2144	44	27·88
5th Nov., 1896	15th July, 1897	8	2110	3	38·01
16th Dec., 1896	7th July, 1897	7	1609	43	26·43
,,	,,	7	1609	43	23·19
17th Dec., 1896	,,	7	1598	1	34·41
24th Dec., 1896	,,	6	1516	3	32·03
30th Dec., 1893	,,	6	1446	3	37·28
31st Dec., 1896	,,	6	1434	23	34·80
,,	,,	6	1434	23	30·36

* Consumption fixed by governor at 3 cubic feet per hour.

There are now 1783 burners in use, out of a total of 2051 ordered by the Committee to date; in 901 of these lamps, 882 being fitted with double and 19 with single burners, the total work ordered to date dealing with 19 miles of streets. A large number have been subjected to most severe tests, extending through the stormy autumn and spring of 1896-7, in positions embracing many of the streets of maximum heavy vehicular traffic and exposure.

It was thought desirable not to allow the lamplighters to undertake, the renewals of mantles, &c., and an inspector has been appointed, whose duty it is to visit each of the lamps two or three times a week, under a carefully-organised route table, during the lighting hours, and to report daily upon the condition of the lamps and as to requisite renewals, which are ultimately carried out by an experienced and independent fitter.

This special supervision and treatment, though most effective, adds 2s. per annum to the maintenance charge per burner, and it is hoped that ultimately it will be found practicable to transfer the work to the ordinary lamplighting staff under a greatly reduced charge.

A carefully prepared register has been kept of each burner, showing the date of fixing and all subsequent renewals, &c.

An Analysis of this has been made, which shows that a considerable number of mantles have been in use for over six months, and others for seven, eight, or nine months, without requiring renewal. A number of these have been brought in for photometric testing, with the results given in Table XLVI.

As already pointed out, the mantles in use for nine months show an average lamp hour life to date of 2841, whilst the average useful life of the mantle over the whole of the system is found to be 1187 lamp hours. The average annual renewals per burner have worked out as follows:—

Mantles	2·6
Chimneys	2·3
Mantle rods	0·23

at a cost of 3s. 11d., to which is to be added the cost of supervision and labour of 2s. per burner, making a gross annual charge of 5s. 11d. in excess of the ordinary flat-flame burner, as compared with £1 4s. 6d. under the first system, being a reduction of 75 per cent. in the maintenance charge of the incandescent gas burner due to the adoption of the new lamp.

For the purpose of enabling the Committee to arrive at an estimate of the relative value of the present incandescent gas lamp as compared with the ordinary flat-flame burner lamp, the following Table XLVII. of the first cost and annual maintenance has been prepared:—

TABLE XLVII.

Description of lamp.	Gas charge at 2s. 6d. per 1000 cubic feet per annum.	Average illuminating power.	First cost of lamp and fixing.	Total annual charge.
	£ s. d.	candles.	£ s. d.	£ s. d.
Double-burner incandescent lamp	2 3 11	80	2 7 5	3 12 9
Single-burner incandescent lamp	1 8 3	40	1 17 4	2 11 2
Ordinary flat-flame burner... ...	1 9 3	16	1 1 1	2 6 3

The above figures, which are useful for comparative purposes, do not supply the most important information, viz.:—The cost of fixing the new lamps in lieu of the existing flat-flame burner lamps, which is as follows, viz.:—

	£	s.	d.
Double-burner lamps	1	11	6
Single-burner lamps	1	1	5

These prices are lower than the first cost in the statement above, owing to the credit allowed for the ordinary lamp superseded, and which is taken into stock at 20 per cent. under first cost, for re-fixing in other parts of the City. This has rendered the further purchase of ordinary lamps unnecessary.

Though the experience of the past three years has conclusively proved that the incandescent gas burner cannot be used with complete success in the ordinary form of lantern, and therefore a somewhat heavy first expenditure is involved in the adoption of the system, the subsequent advantages are so great that a general extension appears irresistible."

Following the above report, Mr. Bellamy further reported on December 9th, 1898:—

Referring to the resolution of the Lighting Committee of the 8th July last, instructing the Superintendent of Street Lighting to report upon the general application of incandescent gas lighting to the whole of the streets of the City, the Committee will recollect that the Superintendent submitted an interim report on the subject on the 2nd September last, pointing out that it was advisable to postpone full consideration of this matter until the Welsbach Incandescent Gas Light Company had completed their arrangements for placing a new series of burners upon the market. The Superintendent has since had opportunities of fully testing these burners, and he proposes to adopt the one known as the "York," which is practically a counterpart of the burner at present in use.

In dealing with the future lighting of the City it will be useful to review what has been accomplished in the way of improvement since the Corporation took over the street lighting in 1894.

To this end a comparison can best be made with the conditions obtaining in 1890—a year uninfluenced by coal or labour troubles, and in every respect comparable with the present conditions affecting the public gas supply, excepting that the selling price of gas was 1d. per 1000 cubic feet lower than at present.

In that year the total number of lamps of every description amounted to 11,330, lighting 276 miles of road, and 1761 courts. The total lighting power of the lamps, assuming the full standard value of the gas for illuminating purposes, of four candles per cubic foot, amounted to 744,699,163 candles, the total cost to the City being £39,000.

In 1894 it was considered desirable to extend the system of reducing the power of street lamps at midnight, which had hitherto been confined to the special lamps in the principal streets, to the whole of the City. As this matter could not be satisfactorily arranged with the Gas Company, who had hitherto carried out the public lighting, except at an increased cost, it was taken over by the Corporation, and resulted in an annual saving of £7000.

In 1895, as a result of negotiations with the Gas Company, it was arranged, under Section 24 of the Gas Works Clauses Act, 1871, and in accordance with the general custom of the country, that the gas for public lighting should be charged at a lower rate than for ordinary purposes. The difference was fixed at 10 per cent., resulting in a further reduction in the lighting charges of £2500, showing a total reduction of £9500. In the same year it was decided to apply the greater portion of this amount to the improved lighting of the City, and the following work has been accomplished:—255 new lamps have been fixed in old streets; 878 passage lamps have been fixed, lighting the back entrances to 20,607 houses; 3¾ miles of road have been lighted by means of electric arc lamps, and 76¼ miles by means of incandescent gas lamps, the total number of lamps in use to date in the old City amounting to 11,646, with an illuminating value of 1,165,838,947 candles, and at a cost of £36,012.

For the purpose of calculating the candle-power of the lamps, the 10-ampère arc lamps have been assessed at 500 candles each, the incandescent gas lamps as yielding an average light, through their average life, of 1187 lamp-hours of 13 candles, and the ordinary flat-flame burners at 4 candles per foot of gas.

For a readier comparison the figures applying to the two years are set out in Table XLVIII., which shows that, notwithstanding 316 additional lamps have been fixed, and the aggregate illuminating power of the old City lamps increased by 56 per cent., the annual charge is £3000 per annum less than in 1890. It will, of course, be understood that the increased illumination is confined to the 150 miles of streets and passages that have been specially dealt with to date.

TABLE XLVIII.

	1890.	1898.
No. of lamps	11,330	11,646
Mileage	276	279
Courts	1,761	1,270
Passage lamps	—	878
Candle-power millions	744⅓	1,166
Cost	£39,000	£36,012

In 1895 the City boundaries were extended, adding 188 miles of road to the City, of which 118 were lighted by 2783 gas and six oil lamps, having an illuminating value of 137,514,384 candles, at an annual cost, according to last published accounts, of £7914 12s. 8d.

The following work has been accomplished in the added areas. The annual hours of lamplight have been increased from an average of 2907 to 3350; 8¼ additional miles of road have been lighted, and the following figures show the past and present illuminating power of the lamps and the annual cost, and from which it will be seen that while the illuminating power of the lamps has been increased by 64 per cent., and the hours of lamplight by 15 per cent., the annual maintenance charge has been reduced by £67.

	1895.	1898.
No. of amps	2,789	3,030
Mileage	118	126½
Candle-power—millions	137½	224
Cost	£7,194	£7,127

In the period 1895 to date, £18,175 has been spent on new works embracing electric, incandescent gas, and passage lighting. The present estimates provide a surplus of £5100 for similar purposes.

In dealing with the resolution of the Committee of the 8th July last, viz.:—"That in view of the success of street lighting by means of the new incandescent gas lamp, the Superintendent of Street Lighting be requested to report on its general application to the whole of the City," the Superintendent may point out that about one-sixth (or 76 miles) of the total mileage of the City is now lighted by incandescent gas lamps, the greater portion of which are in main roads, and are fitted with double burners.

In a report dated 29th September last it was pointed out by the Superintendent that future extensions of this system to the secondary streets could be dealt with by single-burner lamps, and that under such a system, while the illuminating power would be increased to midnight by 146 per cent., and to sunrise by 176 per cent., the annual lighting charge would be reduced by 8s. per lamp.

On these facts it might be argued that the system should be applied generally to the City at once, but the Superintendent would point out that while during the past three years all new works have been charged to surplus revenue without any increased charge to the lighting rate, such a change would necessarily involve the opening of a capital account, the raising of from £20,000 to £25,000, an abnormal extension of the workshop and staff of the Lighting Department, and the possibility that subsequent improvements in incandescent lighting would either be lost to the City or have to be paid for a second time. The Superintendent would therefore strongly recommend that the system be extended at a rate which the surplus funds at the disposal of the Committee will cover.

This sum will provide for the equipment of 2500lamps in each year, the work to be carried out by the present staff, and the entire lighting of the City by means of incandescent gas lamps would be completed in four years, at the end of which the lighting throughout the City would be increased by nearly three times where the single burner lamp is adopted, and by over five times with the double lamp, with a reduction of the permanent charges of between £3000 and £4000.

In continuation of the foregoing reports, Mr. Bellamy presented to the Electric Power and Lighting Committee, on the 18th day of October, 1901, the following *résumé* of the work accomplished up to that date :—

The City Lighting Engineer begs to report that the Committee has now approved the final plan in connection with the application of incandescent gas lighting to the whole of the streets of the City, and it may be useful to review what has been accomplished since the scheme for the re-arrangement of the City lighting was approved.

In 1894 it was considered desirable to extend the system of reducing the power of street lamps at midnight, which had hitherto been confined to the special lamps in the principal streets, to the whole of the City. The lighting and maintenance of the lamps were in the hands of the Gas Company, who could not see their way to deal with the matter in the manner suggested, except at a cost which would have rendered the change uneconomical.

Under a report, dated November, 1893, the City Lighting Engineer recommended that the work of lighting and maintaining the public lamps should be taken over by the Corporation, and an estimate was provided showing that such a change would result in an annual saving of £7000 per annum. This report was approved, and after experiments in various parts of the City the change commenced on 7th November, 1894.

It was further pointed out to the Committee that the general practice throughout the country was for gas to be supplied for street lighting purposes at a lower charge than to ordinary consumers, and as a result of an arrangement, following a reference to arbitration, the price was reduced by 10 per cent., resulting in a further reduction of the lighting charge of £2500 per annum, making a total reduction of £9500.

In November, 1895, it was decided to apply the greater portion of this amount to the improved lighting of the City, and schemes for the reduction of distances between street lamps, passage lighting, electric lighting, and incandescent gas lighting were adopted.

In December, 1898, the Committee decided, on a report of the City Lighting Engineer, to apply the system of incandescent gas lighting to the whole of the City, the extension to be carried out at a rate which the surplus funds at the disposal of the Committee would

TABLE XLIX.—*Comparative Statement as to Annual Cost, Number of Lamps, Candle Power, Mileage, &c.*

OLD CITY.

Year.	Mileage of roads lighted.	Number and description of lamps.				Number of court lamps.	Number of passage lamps.	Aggregate illuminating power.		Price of gas per 1000 cubic feet.	Annual charge (gas, lighting, and maintenance).
		Flat flame.	Incandescent gas.	Electric.	Total.			To midnight.	After midnight.		£ s. d.
1893	272½	11,122	—	—	11,122	1,563	117	466¾	304½	3s.	39,889 12 1
1894	272½	11,018	75	—	11,093	1,544	118	465	304	3s. & 3s. 4d.	41,978 12 6
1895	272¾	10,874	75	—	10,949	1,464	117	462	158¾	2s. 8·4d. & 2s. 6·6d.	31,641 0 0
1896	273	11,003	294	36	11.333	1.426	427	551½	218½	2s. 6·6d. & 2s. 5·7d.	30,006 15 0
1897	273¾	9,371	1486	133	10,990	1,345	712	521¼	302	2s. 5·7d.	31,301 7 4
1898	274	8.517	2990	133	11,640	1 288	1,018	1,158	373	2s. 5·7d.	31,868 19 0
1899	274	6,148	5564	137	11,849	1,204	1,030	1,294	537¼	2s. 5·7d. & 2s. 4·8d.	30,477 5 0
1900	274½	3.808	7969	142	11,919	1,115	1.042	1,504¼	643½	2s. 4·8d. & 2s. 7·5d.	31,639 6 8
1901	274½	2,845	8908	152	11,905	1,084	1,045	1,576½	685	2s. 7·5d.	31,187 11 8

ADDED AREAS.

Year.	Mileage of roads lighted.	Flat flame.	Incandescent gas.	Electric.	Total.	Number of court lamps.	Number of passage lamps.	To midnight.	After midnight.	Price of gas per 1000 cubic feet.	Annual charge (gas, lighting, and maintenance).
1895	128¾	2,789	—	—	2,789	—	—	70	67	3s. & 2s. 10d.	7,194 12 8
1896	131¾	2,882	—	—	2,882	—	—	90¼	39½	2s. 6·6d. & 2s. 5·7d.	8.249 7 2
1897	134	2,695	253	—	2,948	—	—	139	69½	2s. 5·7d.	7,628 1 0
1898	136¾	2 577	458	—	3,035	—	—	174½	81½	2s. 5·7d.	6.507 19 9
1899	139¼	1,724	1521	—	3,245	—	—	260½	138¼	2s. 5·7d. & 2s. 4·8d.	7 249 9 11
1900	142¾	802	2614	—	3,416	—	—	351¼	193½	2s. 4·8d. & 2s. 7·5d.	7.327 16 9
1901	144½	134	3359	—	3,493	—	—	397½	225½	2s. 7·5d.	7,900 0 0

permit, which was estimated to occupy four years. The change, however, has been made in three years, leaving in the present year a surplus of £1000 applicable to other street lighting improvements.

In the six years under review the following work has been carried out in the *old City* at a first cost of £32,956:—358 new lamps have been fixed in the old streets; 928 passage lamps have been fixed, lighting the back entrances to 21,481 houses; 152 arc electric lamps have been erected over an area of 8¾ miles of road; 8908 incandescent gas lamps have been fixed over 248 miles of road.

The total number of lamps in use in the old City amounts to 11,905, with an aggregate illuminating value of 2261½ millions of candles, at an annual cost for lighting and maintenance of £36,187 11s. 8d., the illuminating power being estimated as follows — 10-ampère electric arc lamps, 500 candles; incandescent gas, 40 candles per burner; and ordinary flat flame, at 16 candles.

For comparison the figures applying to the years 1893 to 1901 have been tabulated (see Table XLIX.).

The year 1893 is the last in which the Gas Company had entire control, and it will be seen on reference to the table that the cost of lighting for that year was £40,889 12s. 1d. On the 1st January, 1894, the Corporation took over the lighting, &c., of the special lamps. The following November the first batch of ordinary lamps was transferred to the Corporation, and by the end of December the whole of the lighting of the City was in the hands of the Committee. In addition, the reduction of the charge for gas came into effect on the 1st January, 1895, which brought the lighting and maintenance charges for that year down to £36,167. The figures for 1894 and 1895 do not agree with the published accounts, as in the former year the gas bill was only paid for three quarters, and in the latter year for five quarters.

Comparing the aggregate lighting of the City, it will be noticed that the illuminating power of the lamps has been increased before midnight from 466¾ million candles to 1576½ million candles, or nearly four times; after midnight from 304¼ million candles to 685 million candles, or more than double, whilst the total charges have fallen from £40,889 in 1893 to £39,587 in the present year (the last three months being an ample estimate), or a reduction of £1302.

In 1895 the City boundaries were extended, adding 138 miles of road to the City, 128 miles of which were lighted by 2783 gas and six oil lamps, having an aggregate illuminating value of 137½ million candles, at an annual cost of £7194 12s. 8d.

The following work has since been accomplished:—The annual hours of lamplight have been increased from an average of 2907 to 3577; 15¾ additional miles of road have been lighted, involving the erection of 704 new lamps; 132 miles of road have been lighted by means of 3859 incandescent gas lamps, chiefly in lieu of ordinary lamps.

The aggregate illuminating power of the lamps has been increased as follows:—Before midnight from 70 million to 397 million candles; after midnight from 67 million to 225½ million candles.

These figures indicate an increase in the lighting value of 5½ times to midnight, and 3 times from midnight to sunrise, which has been secured under an additional annual expenditure of £706, or 10 per cent.

The following table L. gives the total charges for all purposes of public lighting for years 1893 to 1901 inclusive, which shows that the total cost of public lighting throughout the old City, including passage lighting, and an average total increase in the aggregate lighting of over 200 per cent., is costing less than in 1893. Deleting the expenditure on the first cost of installing incandescent lighting, the actual reduction is £4702.

TABLE L.

Year.	General lighting maintenance.	Alterations and general removals.	Salaries, establishment charges.	Reduction of distance between lamps. First cost.	Passage lighting. First cost.	Electric lighting. First cost.	Incandescent lighting. First cost.	Total charges.
	£	£	£	£	£	£	£	£
1893	39,889	—	1000	—	—	—	—	40,889
1894	41,978	1000	1477	—	—	—	—	44,455
1895	31,641	2430	2096	—	—	—	—	36,167
1896	30,006	1701	1879	900	500	—	1000	35,986
1897	31,301	2000	2075	534	850	3900	1972	42,632
1898	31,866	2043	2136	—	700	2000	3800	42,545
1899	30,477	2015	2039	—	—	—	7400	41,931
1900	31,639	1251	2401	—	—	—	6000	41,291
1901	31,187	2000	3000	—	—	—	3400	39,587

As already pointed out, the Committee has now at its disposal a surplus of £1000 for use in the present year, and there will be an available surplus next year of between £4000 and £5000 for further improvements.

The City Lighting Engineer would recommend that a large additional extension of passage lighting be made in the coming year, and

if this course is approved plans and estimates will be presented at an early date for the information of the Committee.

These three reports are so typical of what such reports should be, that the author does not feel it necessary to apologise for their inclusion at length.

It is claimed that Liverpool is one of the best lighted cities in Europe. The gas is of exceptionally good quality, and the maintenance of a high standard is secured by means of a rigorous system of testing. It has been well said that " One lesson taught by the Liverpool experiment is that street lighting ought to be regarded as a function quite separate from gas or electricity production. The aim of the works manager is to increase output; the object of the lighting department should be to get the best light at the least cost."

CHAPTER XIX.

HEATING VALUE OF COAL GAS.

THE introduction of the incandescent mantle system of illumination, as well as the greatly extended use of coal gas for cooking, &c., has brought into prominence the calorimetric value of this agent, so much so that it is contended by some that the old-time method of estimating the commercial value of coal gas by ascertaining the quantity of light which a given volume will produce when burnt in a given time in special burners, a process known as "Photometry," will soon be numbered amongst the things of the past, and its place taken by "Calorimetry," or the measure of the heating value of the gas. It will therefore be well to consider this valuable method before passing on to the consideration of matters electrical.

There are two methods of expressing the heating value of a substance: (*a*) In calories, *i.e.*, the quantity of heat required to raise 1 kilo. of water from 0° to 1° C.; (*b*) the British Thermal Unit, or "B.T.U.," which indicates the quantity of heat necessary to raise 1 lb. of water 1°, viz., from 32° to 33° F. In order to convert "Calories" into "B.T.U.s" it will be seen that as the kilo. is equal to 2·2 lb., and the 1° C. to 1·8° F., the calorie must be multiplied by 3·97; thus 1 kilo. = 2·2 lb. water raised 1° C. = 1·8° F., and 2·2 lb. raised 1·8° F. = 3·97 lb. raised 1° F.

The reader must be careful to observe when referring to various text-books that the unit of heat is variously held to be represented by 1 kilo. or 1 gramme of water raised 1° C., by 1 lb. of water raised 1° C., and by 1 lb.

of water raised 1° F. It is unfortunate that these various methods of expression are not unified for simplicity, as they tend to cause considerable and wholly unnecessary confusion. The mechanical equivalent of the British thermal unit was determined by Joule in 1843 to be equal to the energy expended by 772 lb. weight falling a distance of 1ft.

As illumination by gas is often, and will doubtless be still more largely due to its power to raise solid bodies to a state of incandescence, it will be seen that these factors are attaining more importance from the practical point of view every day, apart from the use of gas as a heating agent.

The following Table LI. shows the heating values of the various gases, which in more or less complex mixtures constitute that which is popularly known for convenience as "Coal gas":—

TABLE LI.*

The gases or vapours are measured over water, and therefore saturated with water vapour.

Gas or vapour.		Weight of the gas or vapour in 1 cu. ft. Grammes.	Calorific power, 1 cu. ft., measured at 60° F., 30in. bar. British thermal units.
Hydrogen	H	2·38	321
Or as steam at 212°		—	270
Carbon monoxide	CO	33·05	315
Methane (marsh gas)	CH_4	18·90	979
Acetylene	C_2H_2	30·74	1480
Ethylene	C_2H_4	33·10	1600
Ethane	C_2H_6	34·76	1712
Propylene	C_3H_6	49·76	2348
Propane	C_3H_8	52·04	2478
Butylene	C_4H_8	66·22	3051
Butane	C_4H_{10}	68·62	3228
Pentane	C_5H_{12}	85·12	3943
Benzene	C_6H_6	94·60	3770
Toluene	C_7H_8	108·80	4340

In a communication to the British Association (Sec. B), 1900, Mr. T. Fairley observed :—

In gas made from common coal, with a lighting value of 12 to 17 candles, the heating and lighting values march well together. If any material proportion of air is drawn into the gas before it is consumed, or if the gas first given off from the coal is collected separately from that given off last, the relations of heating and lighting powers are materially affected. Air or nitrogen in gas lowers the lighting power more than the heating power, whereas heavy hydrocarbons have an opposite effect. This latter consideration applies to gas enriched with light petroleum ("carburine") or with benzol, and explains why carburetted water gas has a much lower heating value in proportion than coal gas. In my own and other experiments its heating value is lower by at least 10 per cent. than coal gas of the same lighting power.

---

* This table, which has been kindly checked and corrected by Mr. Fairley, is calculated from the results published by Andrew, Fabre and Silbermann, Thomsen, Berthelot, and others.

In gas made from the same kind of coal the heating and lighting powers march together, and a calorimeter kept constantly working may be used to watch the gas in place of a jet photometer. With mixed gases it would not be applicable; but in that case only a full photometric test would give the true lighting power.

Since gas has been so much used for heating, the measurement of its heating or calorimetric value assumes additional importance. Various calorimeters have been devised by Berthelot in France, Junker in Germany, and Dowson in this country.

The two latter are adapted for continuous working, and are very similar in principle and construction. In both, the products of combustion are made to pass through metallic syphons, so as to give up all their heat to a circulating current of water. Knowing the quantity of water heated during an experiment by so many degrees, the heat units are obtained, and, reading the volume of gas consumed during the experiment, the heat units per cubic foot of gas are calculated. In these instruments the steam produced by the combustion of the hydrogen in the gas is condensed into water. If it is desired to deduct the heat due to this condensation, the water is collected and measured. With such a large surface wet with the condensed water, this correction can only be an approximate one. The amount of water obtained from gas of from 15 to 18 candles averages about 25 c.c. per cubic foot of gas, corresponding to 15 calories, or about 60 British thermal units.

The following average results have been obtained with coal gas:—

TABLE LII.

Lighting power, English standard candles.	Heating power, British thermal units. (Pounds of water heated 1° F., not corrected for steam condensed.)
11	533
12	555
13	578
14	601
15	624
16	648
17	676
18	704

These numbers are comparable with those of Aguitton, but lower, When discussing the paper by the author at the Society of Chemical Industry in December, 1900, quoted on p. 114 *et seq.*, Mr. Fairley further observed:—

> The relation of heating power to lighting power might be put into an algebraic formula; that was to say, one had in all gas a certain proportion of non-luminous gas that might give somewhere about half its heating power, and the rest was due to its lighting constituents. That part was certainly a multiple of the candle power, and one could find the factor which would give the total thermal units from the lighting power. Some people tried to show that the heating power of a gas went down in proportion as the lighting power went up, but that was only apparently so. The result of his own work might be stated thus:—B.T.U. = m (c.p.) + C, in which m was a multiple of the candle-power by a certain factor, and C a constant representing the heat due to the combustion of the non-illuminating constituents which formed a large part of coal-gas. In the gases he had tested m was, approximately = 23·5 and C = 275, so that the formula became—
>
> $$\text{B.T.U.} = 23{\cdot}5\ (\text{c.p.}) + 275.$$
>
> In some cases the heating power of gas had been expressed in heat units per candle, by dividing the observed heating power by the candle-power of the gas, and certain inferences drawn from the fact that as the candle-power rose the heat units per candle diminished. Carrying out this division in the formula:—
>
> $$\frac{\text{B.T.U}}{\text{c.p.}} = \frac{23{\cdot}5\ (\text{c.p.}) + 275}{\text{c.p.}} = \frac{23{\cdot}5\ (\text{c.p.})}{\text{c.p.}} + \frac{275}{\text{c.p.}}$$
>
> it was obvious that as candle-power increased the quotient $\frac{275}{\text{c.p.}}$ must diminish. In other words, the heat due to the combustion of the non-illuminating constituents of the gas could not increase with the lighting power. The apparent diminution was no argument in favour of the use of any particular low-lighting gas for heating purposes. A high lighting-power gas gave a proportionate increase in the heating power.

At the meetings of the Institution of Gas Engineers held on April 30th and May 1st, 1902, two valuable papers reported in the "Journal of Gas Lighting," May 6th, 1902, were read, one by the late Bryan Donkin, and the other by Mr. H. E. Jones. In these the heat factors of various gases were given, and are set out in Table LIII.

If Mr. Fairley's formula be applied to the results obtained by the various experimenters quoted in that table, they give in place of 23·5, numbers varying from 20 to 25 as multipliers of the candle power. To divide the total

TABLE LIII.

Authority.	Gas.	Heating value per cubic foot, B.T.U.	B.T.U. per candle.
B. Donkin	London supply	600	
,,	Mond	148	
H. L. Greville	12·9 candle power	541	41·9
,,	13·9 ,,	556	40·0
,,	14·3 ,,	569	40·0
,,	13·5 ,,	577	42·7
,,	13·8 ,,	588	42·4
,,	13·8 ,,	591	42·5
,,	15·4 ,,	616	40·0
,,	16·2 ,,	628	39·0
,,	15·6 ,,	652	41·8
,,	16·0 ,,	652	40·8
,,	16·6 ,,	669	40·3
,,	16·4 ,,	672	41·0
,,	16·6 ,,	691	41·6
,,	16·5 ,,	672	41·0
H. A. Humphreys	Coal gas (? London)	675	—
H. F. Hills	Coal gas	624	—
A. Paddon	14·0 coal gas	580	41·4
M. Verdier	Low grade coal gas	601	—
,,	High grade coal gas	709	—
H. L. Greville	16·5 Stepney gas	672	40·7
,,	16·0 Stepney gas	653	40·8
,,	16·0 mixed with 5 per cent. of air	616	—
,,	16·0 mixed with 10 per cent. of air	574	—
H. E. Jones	Dowson Gas	150	—
,,	Mond gas	155	—
A. G. Glasgow	Carburetted water gas and low grade coal gas c. 544	470	—
,,	Water gas	435	—
Average			41·0

Mr. Greville's results are not corrected for steam condensed.

number of heat units obtained by the observed candle power is to overlook the fact that coal gas contains a large proportion of non-luminous constituents, and that the luminosity, as commonly tested, is due to comparatively small proportions of certain hydrocarbons.

By plotting these various results with those given in Mr. Fairley's table and tabulating the mean curve, we obtain the following scale, viz.:—

TABLE LIV.

Description of gas.	B.T.U.'s per cu. ft.
Dowson gas	150
Mond gas	151
Water gas	435
Carburetted water gas and low grade coal gas ...	470
Coal gas 11·0 candle power	500
„ „ 11·5 „	514
„ „ 12·0 „	530
„ „ 12·5 „	545
„ „ 13·0 „	560
„ „ 13·5 „	576
„ „ 14·0 „	592
„ „ 14·5 „	607
„ „ 15·0 „	623
„ „ 15·5 „	638
„ „ 16·0 „	652
„ „ 16·5 „	667
„ „ 17·0 „	682
„ „ 17·5 „	698
„ „ 18·0 „	714
16·0 c. coal gas + ·5 per cent. of air	616
16·0 „ „ „ + 10 „ „ „	574

As illustrating the latest outcome of the various efforts made to provide a thoroughly reliable instrument for the purpose of readily ascertaining the calorific value of coal and other gases the following account of the calorimeter devised by Messrs. Simmance and Abady, and the method of using it, will be of interest

The principle upon which this instrument is based was first introduced by the late Mr. F. W. Hartley in 1883 for the purpose of testing the gas used by the author and the late Professor Wm. Foster, and Mr. D. K. Clark, in testing the various exhibits of burners and gas stoves in connection with the International Electric and Gas Exhibition at the Crystal Palace in 1882-1883; and which was described by him in a report to the Committee of the Gas Section appointed by the Gas Institute (see Vol. 1 of the report of that Committee).

In this instrument the calorific effect is calculated from the rise in temperature of an ascertained flow of water, due to the combustion of a measured quantity of gas. The action of the instrument (Fig. 156) is clearly shown by reference to the section and plan shown in Fig. 157. The water, from a source maintaining a constant pressure, enters at A and passes through the tap B, round the bulb of the thermometer D (Fig. 158), and along the course shown by the arrows, through the annular chambers E E E E, down the tubes F F F F, and up through the tubes G G into the upper receptacle H, round the bulb of the thermometer J, and thence by the outlet K. The pressure of the water supply is indicated by the float in the water tube C. The heated water is discharged by the waste tube L into the swinging funnel (Fig. 159), which is diverted at the commencement of each experiment, so as to discharge the heated water into the measure M.

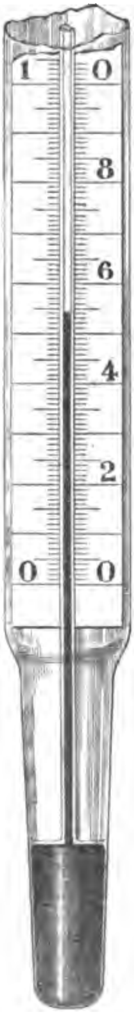
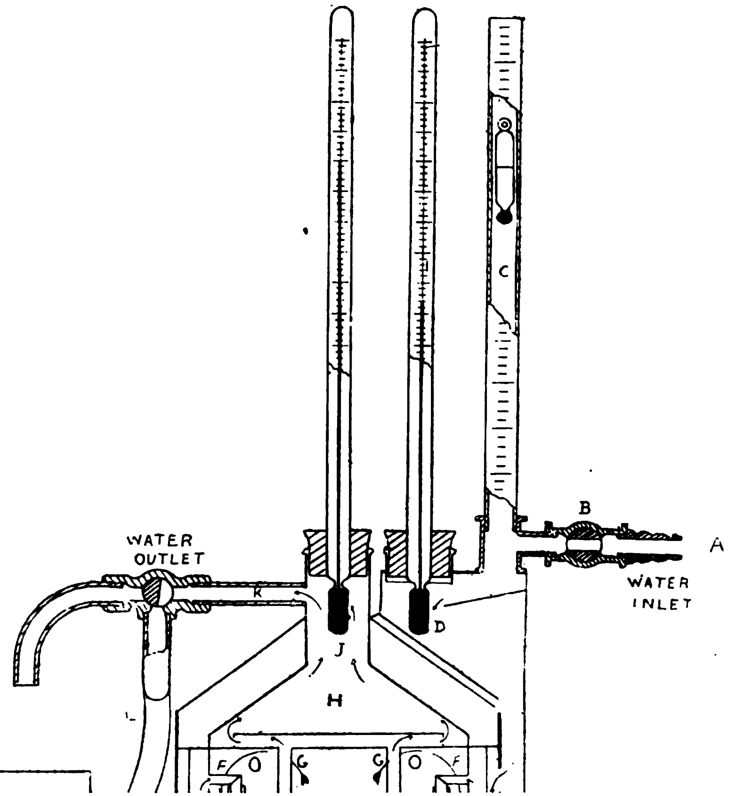


Fig. 158.
Full size.

When the lighted burner S is placed in position the products of combustion rise up the centre shaft N, and, partially condensing in the chamber O, drop down the annular passage P P P P, and issue, at the temperature of the original gas, as carbonic acid, non-condensible products, and water, at the lip Q;



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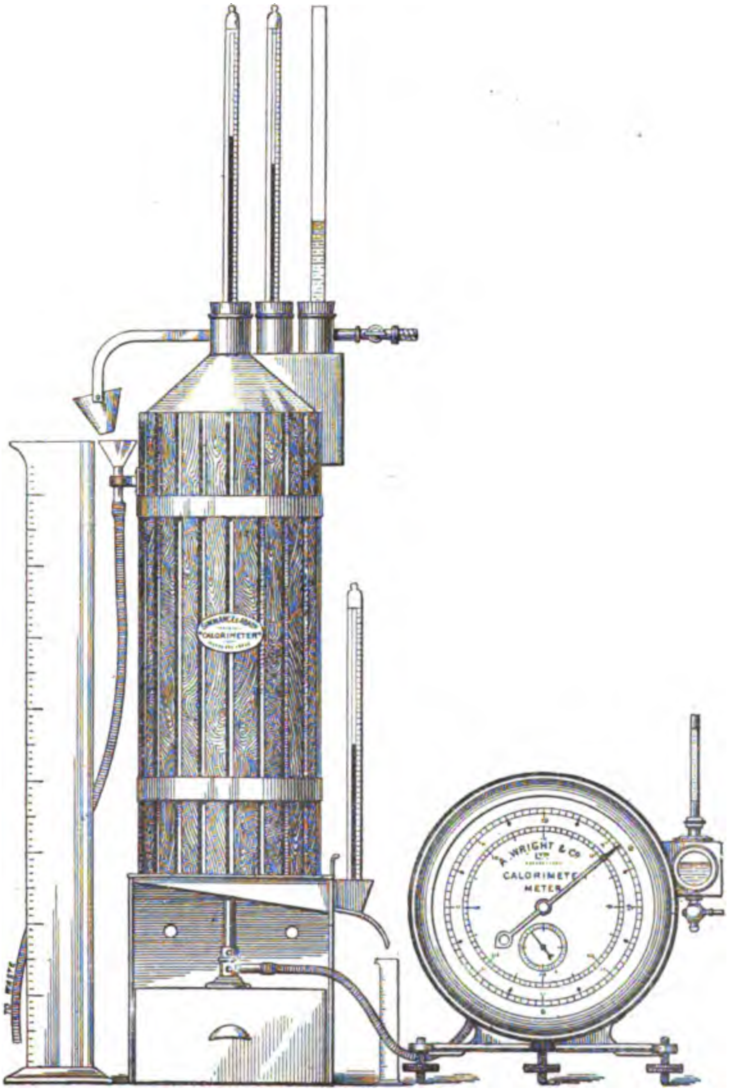

Fig. 159.

the condensed water being collected in the graduated measure R.

The specific advantage of this instrument is that a succession of, say, three short tests can be made, and if any variation of temperature occurs, these can be repeated, the time occupied being only a matter of seconds. In this way it is possible to keep the calorimeter constantly at work, thereby enabling a test to be made at any time of the calorific power of the gas.

The following instructions are issued with the instrument by the makers:—

1.—Turn on the water and let it run freely through the calorimeter to waste till the two thermometers read alike. See that the overflow is running at such a rate as to keep a constant level in the gauge tube C.

2.—Light the gas burner, place it under the calorimeter, and lift it till high enough to enable the stand to be placed underneath it. See that the burner rests in the space prepared for it on the stand, in order that it may be central with the tube N. Let the water run and the gas burn until the reading of the outlet thermometer is steady. Note its difference from the inlet temperature.

3.—As the meter hand passes a marked division, say zero, turn the water outlet funnel into the 900 c.c. measure, and as the meter hand passes a second marked division, say 12, switch the funnel back to the waste funnel. Read the quantity of water which has thus been discharged into the 900 c.c. measure.

The known data will then be—

(*a*) Difference in temperature.
(*b*) Quantity of gas passed.
(*c*) Quantity of water heated.

The test should then be repeated, and an average of the readings taken, which may, for instance, read thus—

Gas burned.	Water heated.	Difference of temperature.
12 (600ths c. ft.) ...	322 c.c. ...	21·7° − 12·5° = 9·2°

On referring to the tables supplied with the instrument, under 12 in the top line, and opposite 322 in the left hand column, will be found the factor 16·1, which on being multiplied by 9·2° = 148·12 calories per cubic foot of gas.

This is the gross value, and is not developed in everyday use, except, perhaps, by a condensing stove under certain circumstances. The net calorific power is obtained by deducting the amount of heat which ordinarily escapes as steam, &c. To ascertain this, the small measure should be placed under the products outlet lip when first the actual experiment commences, noting the position of the *cumulative* pointer on the meter. When a complete foot has been burned, remove the measure and note the number of c.c. of water collected. Multiply this by 0·6. The result is the number of calories which should be deducted from the *gross* to obtain the net value.

To transform the calorie result into British thermal units, multiply the calories formed by 3·97, as previously indicated.

It will be seen that with this calorimeter the method of estimation may be varied by burning a variable quantity of gas and passing a fixed quantity of water, the tables being suitable also for this.

For accurate work it is necessary to correct the quantity of gas consumed during the test, for temperature and barometric pressure, by means of the table given in the instructions of the Gas Referees in the appendix, and to observe that the temperature of the escaping products of combustion should be at the same temperature as that of the gas as it leaves the meter.

CHAPTER XX.

THE GENERATION OF DYNAMIC ELECTRICITY BY MECHANICAL MEANS.

IN the preparation of the following chapters on the production and utilisation of electrical energy, the author has to acknowledge the valuable collaboration of Mr. G. E. Moore, A.M.I.Mech. E., who has kindly made the series of original drawings which accompany the text. These will doubtless be of great assistance to the reader. It is not pretended that these chapters should take the place of a text-book on electricity. They are merely intended to assist the general reader to form a fair idea of the processes involved in the production of electrical energy, and to point out the road to those who may be desirous of following the technical intricacies of the subject further. Some of the points, such as those relating to "potential," have been considered from a new standpoint, and will, it is hoped, be of assistance to those who have hitherto had a difficulty in following technical electrical phraseology.

From the poles of a magnet lines of force issue radiating in all directions, in the same way as the rays of light issue from some luminous object, and consequently follow the law of inverse squares as explained on page 20, being quite close together on the surface of the magnet, and diffusing themselves over an ever-increasing area as the distance from the magnet is increased.

We can, however, to some extent control the diffusion of the rays of light from a candle or lamp, and by the use of suitable reflectors concentrate them on some limited area which we wish to illuminate, leaving the surrounding space almost in complete darkness; and we can also, to some extent, control the diffusion of the magnetic lines of force issuing from the poles of a magnet by placing two unlike poles opposite to each other, whereby the lines of force will travel from one to the other almost in parallel straight lines.

While stating definitely that lines of force issue from the poles of a magnet, we do so for the sake of convenience, and in order to present some tangible picture to the mind's eye, for we cannot, of course, see such lines, although their effect can be made visible to us by sifting iron filings over a piece of stiff paper resting on a magnet. For the sake of convenience also, we imagine the lines of force as issuing or being repelled from the N or north-seeking pole of a magnet and entering or being absorbed into the S or south-seeking pole; and further, for the sake of convenience, we imagine that a specific strength of magnet or magnetic force is represented by a certain number of lines of force, and that by increasing this number for a given area the specific strength of the magnet is increased.

Magnetic poles of the same kind repel one another, while those of opposite kinds attract one another.

The term *magnetic field* was used by Faraday to designate the entire space or region through which the magnetic lines of force travel or are diffused.

If an electric current be passed through a conductor, such as a copper wire, magnetic lines of force circle round it.

In a series of experiments made by Ampère, he discovered that if a current be passed through two parallel conductors placed in close proximity to each other both in the same direction, the lines of force circling round them act on each other in such a way as to cause the conductors to approach one another; but if the current be passed through them in opposite directions, the lines of force circling round the conductors cause them to recede from one another.

In Fig. 160, *a* and *b* are two parallel conductors having an electric current passing through them both in the same direction and away from the onlooker. The magnetic lines of force circle round them both in the direction in which the hands of a clock turn, and they mutually attract one another.

In Fig. 161, the current in *b* is reversed, so that it flows towards the onlooker, while that in *a* remains as before. The lines of force circle round the two conductors now in opposite directions, and they mutually repel one another.

It will be seen, however, that on adjoining sides in Fig. 160, where the lines of force circling round both conductors are nearest each other they travel in opposite directions, while in Fig. 161 they travel in the same direction; consequently we may say that lines of force travelling in the same direction—the same as like poles—repel one another, and lines of force travelling in opposite directions—the same as unlike poles—attract one another.

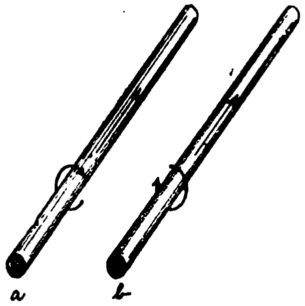

Fig. 160.

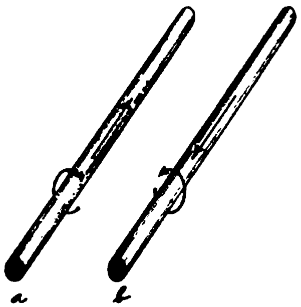

Fig. 161.

If we take a coil of copper wire and pass an electric current through it, magnetic lines of force circle round the wire as shown in Fig. 162; but if the coils be wound close together so that they nearly but not quite touch one another, some of the lines of force escape through the air instead of circling round the wire, and pass right through the inside of the coil, out at one end, back over the outside, and through the inside again, and so on, thus circling round a series of wires instead of round each wire singly.

Such a coil is called a *solenoid,* and is a feeble magnet, having a N pole where the lines of force issue from it, and a S pole where they enter it again. A bar of soft iron or steel placed inside a solenoid becomes magnetised, for the iron offers less resistance to the passage of the lines of force circling round the coils of the solenoid than the air does, consequently most of them pass through the iron instead of circling through the air round the coils. We have then an *electro-magnet* (see Fig. 163) having exactly the same properties with respect to attraction and repulsion as all ordinary permanent magnets.

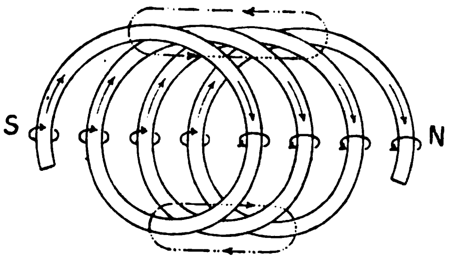

Fig. 162.

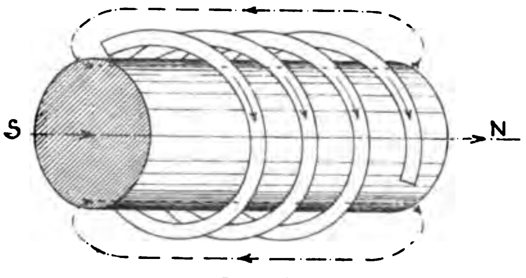

Fig. 163.

The iron must not come in contact with the coil, however, otherwise the greater part of the electric current will escape through the iron instead of passing through the coil. The coil must therefore be made of insulated wire; for although the insulating medium prevents the electricity from escaping, it offers very little resistance to the passage of magnetic lines of force, and not more than air does, which is itself a very good electric insulator. The strength of the electric current flowing through a wire determines the number of the magnetic lines of force circling round it; consequently the stronger the current passing through a coil and the greater the number of turns in it, the more strongly magnetic the iron becomes, until the point of saturation is reached beyond which iron cannot be magnetised.

By the word *potential* used in connection with electricity we mean a latent power capable of producing an *electromotive force,* that is, a force to move electricity, thus causing a current to flow.

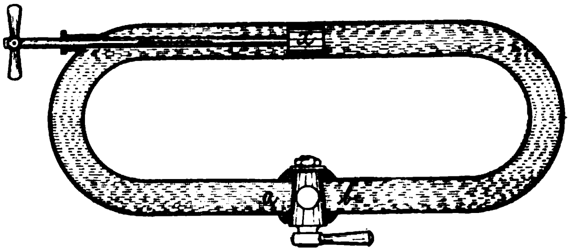

Fig. 164.

If a conductor be of the same electric potential throughout, the electricity in it is in equilibrium, and there is no tendency for it to flow. If one end of a conductor is of a higher potential than the other, this is at once manifested as a greater electromotive force at one end than at the other; and if the two ends are connected so as to allow the electricity a free passage, the electromotive force causes a current to flow until electric equilibrium is restored throughout the conductor.

To illustrate this we will take a bent tube filled with air and having its two ends communicating with one another through a tap which may be opened or closed (see Fig. 164). A small piston *x* fits perfectly in the tube, so that no air can escape between it and the sides of the tube.

The potential, or pressure of the air, is equal throughout the tube; there is, therefore, no tendency for the air to flow when the tap is opened, so that there is a means of communication between the two ends.

If the piston be now forcibly moved in the direction indicated by the arrow, the air will be compressed at *a* and there will be a partial vacuum formed at *b*; the air is therefore of a higher potential at *a* than at *b*, and this difference of potential produces a force tending to move the air from *a* to *b* until both ends are at equal potentials, and equilibrium is restored; but this cannot take place until the tap communicating between the two ends is opened.

This represents exactly what takes place in an electrical conductor when a current passes through it.

By certain means the electrical equilibrium can be disturbed so that the electricity at one end is of a higher potential than at the other, and this at once produces an electromotive force, tending to move the electricity from the end where the potential is high to that where it is low, and thereby restore equilibrium; but this cannot take place until the two ends of the conductor are connected, thus allowing the electricity to flow from one end to the other. The potential at one end may even be increased to such an extent as to cause the electricity to force itself a passage through the air or any other insulating material surrounding the conductor if the ends are not connected, just as the air in a tube may be compressed to such an extent as to burst the tube.

Fig. 164 may be taken to represent an ordinary air compressor or hydraulic pump, and the connection between the two ends *a* and *b* need not be made direct, as shown in the figure, but may be made by means of pipes entering the tube at *a* and *b*, so that the pressure at *a* may be utilised to overcome some resistance, such as the ram of a press at a considerable distance away before it is allowed to escape to *b*. In the same way the electromotive force, caused by a difference of potential in a conductor, may be utilised to overcome a resistance such as an arc or an incandescent lamp at a considerable distance away, by compelling the current to flow through it in its passage from the end of high to that of low potential.

Faraday discovered that an electric current passes along a wire of copper, or any other conducting metal having its two ends connected with one another, if it is moved across one pole of a magnet so as to cut through the lines of force issuing from it.

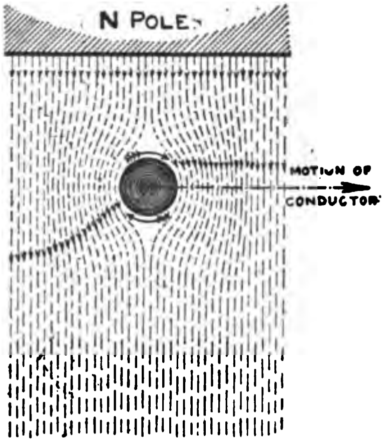

Fig. 165.

Fig. 165 represents the N pole of a magnet, and shows a section of a conductor in the midst of the magnetic field in close proximity to the pole from which the lines of force issue, as indicated by the dotted lines and arrow heads.

Now if the conductor be moved parallel to the surface of the magnet, as indicated by the arrow, the tendency will be for opposing lines of force to circle round the conductor in order to resist the motion. It is obvious that on the right-hand side of the conductor the lines of force which will circle round it will be in the same direction as those issuing from the magnet, because like forces repel one another, and they would thereby resist the motion of the conductor; also, on the left-hand side of the conductor the lines of force which will circle round it will be in an opposite direction to those issuing from the magnet, because unlike

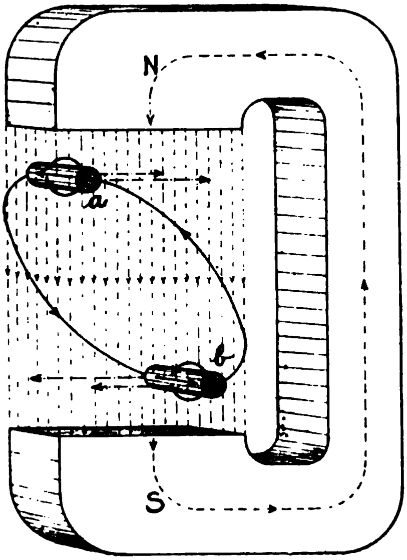

Fig 166.

forces attract one another, and they would thereby also resist the motion of the conductor. The lines of force would circle completely round the conductor in the direction in which the hands of a clock turn, and would cause a current of electricity to flow along the conductor away from the onlooker.

Fig. 166 represents a curved magnet, typical of such as are used in the construction of dynamos and motors, whose lines of force issue from the N pole and enter in at the S pole, passing through the iron back to the N pole again in a continuous circulation. The mutual attraction between a N and a S pole prevents the lines of force from becoming scattered and diffusing themselves through the air, but induces them to take the shortest way through the air space intervening between the two poles, and to travel in almost parallel straight lines.

In the figure, *a* and *b* represent two conducting wires whose ends are connected together, which may be assumed to represent two of the conductors which are assembled on the periphery of the armature of a dynamo or motor. They are moved in the directions indicated by the arrows, thereby causing magnetic lines of force to circle round them, as shown by the curved arrows, and an electric current to pass along them.

On the right-hand side of *a*, that is, on the side towards which it is moved, the lines of force will circle round the wire in the same direction as those issuing from the magnet, so that they repel one another, and thereby produce a force in opposition to that which moves the wire. On the left-hand side of *a*, the lines of force will circle round it in an opposite direction to those issuing from the magnet, so that they attract one another; and they also produce a force in opposition to that which moves the wire.

The magnetic lines of force will circle round the wire in the same direction as that in which the hands of a clock turn, and the current will flow away from the onlooker, as shown by the arrow on the wire itself.

Again, on the left-hand side of *b* the lines of force will circle round the wire in the same direction as those entering the S pole, so that they repel one another, while those on the right-hand side will travel in an opposite direction, so that they attract one another, thus setting themselves in opposition to the movement of the wire.

The lines of force will circle round the wire in a direction contrary to that in which the hands of a clock turn, and the current will flow towards the onlooker.

Referring back to Fig. 163, let the coil have its two ends connected together by a copper wire with no current passing along the coil, and let the iron core represent a permanent magnet whose lines of force travel from the N to the S pole right round its entire surface, in the direction indicated by the dotted lines and arrow heads, within, instead of outside, the coil as shown in the figure.

When the N pole of the magnet is inserted into the coil, the wire cuts through the lines of force issuing from it, and this causes magnetic lines of force to circle round the wire, which set themselves in opposition to the movement of the magnet, and an electric current passes along the coil in the direction shown by the arrows; which direction is reversed as the magnet passes right through the coil, when the lines of force entering the S pole are cut through by the wire, and the current will flow in a contrary direction to what it did as the N pole was inserted into the coil, and as indicated by the arrows on it. This is a fundamental principle of the action of dynamos, and will be dealt with more fully later on.

The following statements summarise the whole process of the production of an electric current by the application of Faraday's discovery :—

In a magnetic field having an electrical conductor near to and parallel with its surface, if the number or direction of the lines of force issuing from it be altered, the electrical equilibrium in the conductor is disturbed, so that there is a difference of potential between its two ends, giving rise to an electromotive force; and if the ends of the conductor be connected, a current of electricity flows through it.

The same happens if the conductor be moved so as to alter the number or direction of the lines of force influencing it, and only so long as an alteration is taking place.

If the conductor remains stationary under the influence of a constant magnetic field, or if either or both be moved, but under such conditions that, in relation to the number or direction of the lines of force acting upon it, the conductor remains unaltered, its electrical equilibrium remains undisturbed, and, therefore, no electromotive force is instigated to cause a current of electricity to flow.

The production of an electric current by this process goes by the name of *induction*, and the current or the electromotive force is said to be *induced.* The electromotive force caused by a difference of potential in a conductor is measured in *volts* just as a pressure of air or water is measured in pounds per square inch ; and the electricity passing along a conductor is measured in *ampères,* just as the quantity of water flowing through a pipe is measured in gallons per second.

Corresponding to the friction of the water or air against the inner surface of the pipe through which it is flowing, there is a resistance offered by the conductor to the flow of the electric current, and this resistance is measured in *ohms.*

If an electrical conductor be moved mechanically in a plane at right angles to the direction of the lines of force issuing from a homogeneous magnetic field, the induced magnetic lines of force circling round the conductor travel in such a direction that they *resist the movement.*

If under otherwise similar conditions the movement of the conductor be other than at right angles to the lines of force issuing from the magnetic field, the resistance opposed to the movement of the conductor is dependent only on the component of the space traversed at right angles to the direction of the lines of force, that is, *on the number of lines of force a conductor cuts through in a given time.* On this depends also the pressure as measured in volts of the induced current.

It, for the purpose of illustration, we assume that the lines of force issuing from a magnetic field do not radiate, but travel parallel to one another, and that their power therefore does not decrease as the distance increases, also that the pressure of the current induced in a conductor moved one foot in one second at right angles to the line of force be one volt, to obtain the same pressure in a conductor moved at an angle of, say, 45 deg. to the direction in which the lines of force travel, it would have to cut through the same number in the same time, and the distance it would have to travel

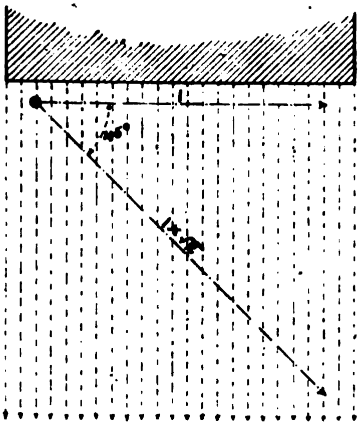

Fig. 167.

would therefore be 1 × $\sqrt{2}$ft. in one second. (See Fig. 167.)

If under the same conditions the conductor be moved *parallel to the direction* of the lines of force it would cut through *none*, and no alteration would be taking place in the conductor in relation to the lines of force; consequently no current would be induced in it.

According to Lenz's law, if the lines of force issuing from a magnetic field, having an electrical conductor within their influence alter, the induced current or electromotive force in the conductor is such that it resists the alteration.

The foregoing summarises shortly the principles underlying the construction of all modern electric generators or dynamos and motors. We will now briefly consider the different kinds of machines used for lighting purposes and for the transmission of power.

CHAPTER XXI.

ELECTRIC GENERATORS.

Every electric generator or motor consists of three essential parts, viz.:

(1) The so-called field magnets, producing a magnetic field.

(2) The armature, carrying a series of conductors which, in a generator, on being revolved, cut through the lines of force in the magnetic field; or which, in a motor, when a current of electricity passes through them, cause the armature to rotate.

(3) An apparatus for collecting or distributing the current.

The field magnets consist of one or more pairs of electromagnets, each pair having one N and one S pole, having iron or steel cores surrounded by a coil of insulated copper wire. The armature consists of a laminated iron core having insulated copper wires, or bars of copper, arranged on its outer surface, parallel with each other and with the axle of the armature.

The iron core of the armature is made either in the shape of a ring or in the shape of a cylinder; but in both cases the copper wires or bars are bent to the shape of a letter U, so that their two ends appear on the same side of the core. These U-shaped wires or bars will be hereafter referred to as the armature *coils.* (See Figs. 168 and 169.)

The former arrangement is convenient, for it facilitates the removal of any damaged coil for repairs; whereas with the latter this is difficult, on account of the coils overlapping each other at one end; but it has the advantage over the former that only half the quantity of wire is required, for that part of the coil which is inside the ring is useless so far as the generation of the current is concerned.

The ends of all the coils are connected to the apparatus on the armature spindle for collecting or distributing the current.

The iron core, as previously explained when describing the electromagnet, tends to prevent the lines of force from circling round each separate conductor when an electric current passes through it, but compels them to travel right round the armature, whereby they can be more effectively utilised.

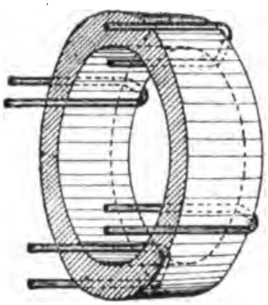
Fig. 168.

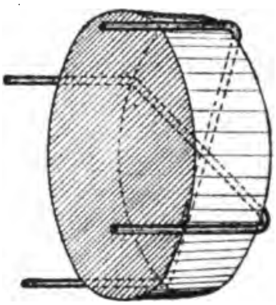
Fig. 169.

Fig. 170 represents a continuous-current generator having one N and S pole placed diametrically opposite to each other, with the space between them occupied by the armature.

Dynamos and motors may be divided into two classes, according to whether they generate or are set in motion by continuous or direct-current, or by an alternating current.

By a continuous or direct-current we understand a current which flows always in one direction ; whereby a certain terminal of the machine is always of a high potential, while another is always of a low potential, and the current flows unvaryingly from the high to the low potential terminal.

By revolving the armature of a dynamo the electric equilibrium in its coils is disturbed, so that at one end the electricity is of a high potential, and at the other end of a low potential, and as previously described, a current of electricity flows from the one to the other as soon as the two ends are connected by a conductor.

The connection between these two ends we will hereafter refer to as the circuit, and this may be of any length, even as much as many hundreds of miles if necessary.

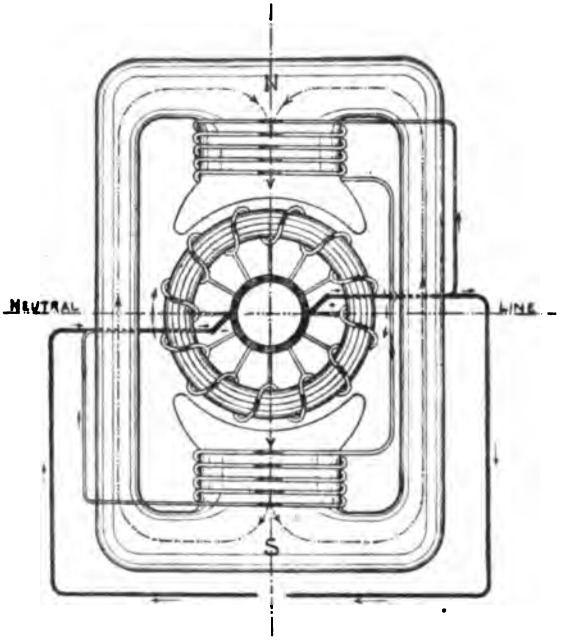

Fig. 170

To utilise the current we intercept the circuit at any point by a lamp or a motor, so that the electricity overcomes a certain resistance and does work in its passage from the terminals of the armature coils of the generator which are of a high, to those which are of a low potential. The high potential electricity corresponding to a pressure of air we call positive, while the low potential electricity corresponding to a vacuum we call negative; so that a current which starts from one terminal of a generator and enters one terminal of a motor or lamp is positive, while that which leaves the other terminal of a lamp or motor and enters the other terminal of the generator is negative.

An alternating current does not flow always in one direction, but flows alternately backwards and forwards between the terminals of the generator; for the coils of the armature reverse their ends of high and low potential with a frequency which often exceeds one hundred times in one second.

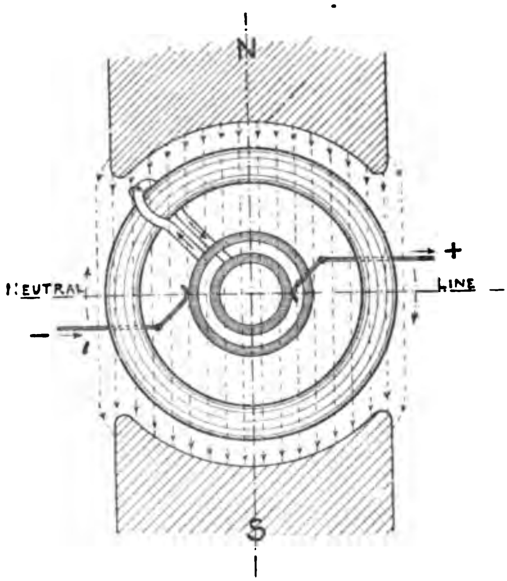

Fig. 171.

Single-phase Alternating Current.—Fig. 171 shows the N and S poles of a two-pole generator, placed diametrically opposite to each other, and occupying the space between them the armature core with a single coil wound on it, having its two ends fastened to two insulated metal rings, shown on the figure, to enable them to be clearly seen, of two different diameters. Each of these rings has a sliding contact pressing against its surface by means of a spring for collecting the current.

These contacts, known as the brushes, are fixed to some immovable part of the machine, and are always in contact with the rings, so that the electricity as it is generated can flow into the circuit while the armature is revolving.

If the armature be revolved clockwise as indicated by the arrows, when the coil is on the left-hand side exactly on the neutral line approaching the N, and receding from the S pole, it momentarily moves exactly parallel with the lines of force travelling from the N to the S pole, and cuts through none, consequently no lines of force circle round it, and no current flows through it.

Next instant it commences cutting through the lines of force, at a sharp angle at first and slowly compared with the distance it travels, so that lines of force commence to circle round it, which set themselves in opposition to the rotation of the armature, and a feeble current commences to flow through it.

The current gradually grows, increasing as the distance between the coil and the vertical centre line decreases. As it crosses the lines of force at right angles, the coil cuts through the greatest number in a given time, and the induced current flowing through it is at its maximum pressure.

Applying Lenz's law, the lines of force circling round the coil will travel in a clockwise direction as indicated by the curved arrow in the diagram, so as to resist the movement of the armature, and the induced current will flow away from the onlooker, as shown by the arrows on the coil itself. Or, from the brush on the left-hand side as a negative current, through the coil to the brush on the right-hand side, and out into the circuit as a positive current. Directly the coil commences to recede from the vertical centre line the induced current commences to fall, becoming more and more feeble as the coil approaches the horizontal or neutral line on the right-hand side, where, as it crosses it, the coil moves parallel with the lines of force, cutting through none, so that the current momentarily dies away.

The coil now commences to approach the S pole. As the lines of force travel from the N to the S pole, their impact on the coil is in a contrary direction to the impact as the coil approached the N pole; the lines of force, circling round the coil, will therefore travel in a contrary direction to what they previously did, and a negative current will now enter the brush on the right-hand side, flowing through the coil to the brush on the left-hand side, and entering the circuit there as a positive current.

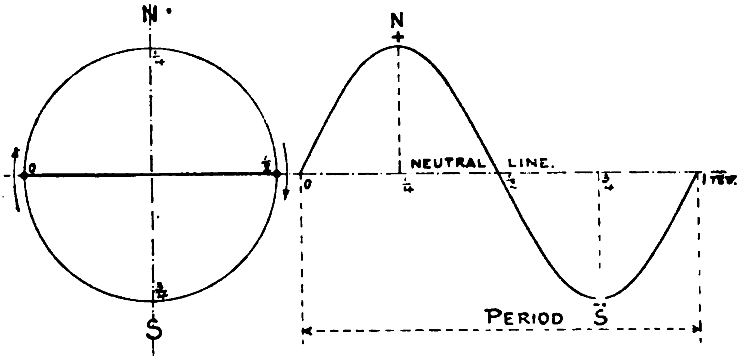

Fig. 172.

The current gradually grows until the coil reaches the vertical centre line at the S pole, where it again attains its maximum pressure. On the completion of the revolution, the current again falls to zero. This operation will be clearly understood by referring to the curve shown in Fig. 172, which represents the character of the current flowing through the brush on the right-hand side in Fig. 171.

The first half of the curve represents the current generated during half a revolution of the armature as the coil travels from the neutral line on the left-hand side, crossing the vertical centre line at the N pole after a quarter of a revolution, to the neutral line on the right-hand side, whereby the electricity will be at a high potential at that end of the coil connected with the smaller of the two collecting rings having the right-hand brush in contact with it, and at a low potential at the end connected with the larger ring, which communicates with the left-hand brush.

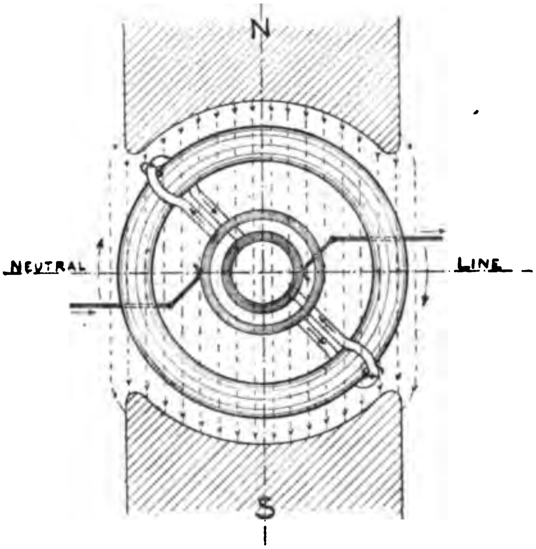

Fig. 173.

The current consequently flows through the circuit from the right-hand brush as a positive current to the left-hand brush as a negative current. The second half of the curve represents the current generated as the coil travels from right to left, crossing the vertical centre line at the S pole, whereby the high and low potential ends of the coil are reversed, causing the current to flow in a contrary direction; or from the left-hand brush as a positive current to the right-hand brush as a negative current.

The height of the curve above and below the neutral line indicates the positive and negative pressures of the current at any moment during one revolution of the armature. The curve shows, too, that this is an alternating current; for it flows alternately in opposite directions through the circuit from one terminal to the other.

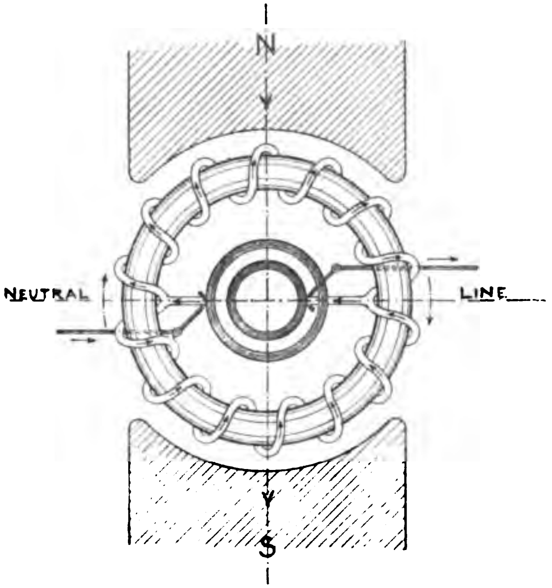

Fig. 174.

If we place a second coil on the armature exactly diametrically opposite to the first, and connect their ends to the collecting rings in the manner shown in Fig. 173, having the low potential end of the coil approaching the N pole connected to the same ring as the low potential end of the coil approaching the S pole, and both the high potential ends to the other ring, the current generated by each coil as it cuts through the lines of force from the N and S poles of the magnets will combine where the ends meet and flow through the circuit simultaneously as one current; so that a greater quantity is generated with two coils arranged in this way than with only one without altering its character, which may still be represented by the curve shown in Fig. 172.

It is obvious, however, that if the ends of the coils are wrongly connected the current generated by the one coil will be exactly neutralised by the current generated by the other coil, and none will flow through the circuit.

By using two coils instead of one, thus generating twice the quantity of current during each revolution of the armature, the size of the wire forming the circuit must be increased to twice its former area to avoid injurious heating, thus offering a greater resistance to the flow of the current.

By winding the coils several times on the armature core before connecting their ends to the collecting rings instead of only once, as shown in Figs. 170 and 174, a greater length of wire is exposed to the action of the lines of force passing between the poles of the magnet, resulting in more lines of force being cut through by the wire during each revolution of the armature, thereby increasing the pressure of the current; but its character remains unaltered, and may still be represented by the same curve.

In Fig. 174 each coil is wound seven times on the core of the armature, and there are therefore seven lengths of wire opposite each pole cutting through the lines of force at the same time, consequently the pressure of the current generated would be seven times as great as if each coil were wound only once round the core, assuming that the armature revolves at the same speed in both cases. It is, of course, immaterial whether the ends of the two coils are joined together before connecting to the collecting rings, or whether the four ends are connected separately; as in both cases the current flows from one to the other in the same manner. The same result could be obtained with a pair of coils wound only once round the core, by increasing their length and that of the surface of the magnet poles sevenfold; so that the same length of wire is exposed to the action of the same number of lines of force.

Or, to obtain the same pressure of current in both cases, the speed with which the armature revolves in the one must be seven times as great as that with which it revolves in the other.

The connections between the coils and the collecting rings can be made in a great many different ways, so as to obtain different pressures or voltages, and different quantities or ampères of current.

In Fig. 174 seven coils are connected in series in each half of the armature, the two sets of seven being connected in parallel.

If, with this arrangement, by revolving the armature at a certain speed a current of seven volts and two ampères is generated, by connecting all the coils in series a current of fourteen volts and one ampère would be generated; or by connecting all the coils in parallel a current of one volt and fourteen ampères would be generated.

The coils would all be in series if the current were made to pass through all before being allowed to pass into the collecting rings; or they would all be in parallel if each single coil had its two ends connected direct to the collecting rings.

With a high-voltage current the insulation of the wires must be much more perfect than with a low-voltage current, just as with water at a high pressure, the material and thickness of the tubes through which it flows must be better and greater than if the water were at a low pressure. The area of the wires must be in proportion to the ampères of the current just as the area of a tube must be in proportion to the quantity of water flowing through it.

The electric *unit of power* is the power of a current of one ampère at a pressure of one volt. This unit is known as one *volt ampère* or one *watt*, and is equivalent to about $\frac{1}{746}$ of one horse-power.

One thousand watts is called one *kilowatt*, and this is approximately 1⅓ horse-power.

Referring back to Fig. 172, any one of the recurring states of the current with respect to pressure, that is the particular state of the current at any given instant, is called its *phase.* It will be seen by the figure that the current is constantly assuming a different phase: yet it is only a single-phase current, for at any given instant it has only one phase.

The curve represents one whole cycle of operations called a *period*; that is the current induced in a coil during its transit from zero to its maximum positive pressure, back again to zero, then to its maximum negative pressure, and back once more to zero, where one whole cycle of operations or one period is complete, and a new one commences exactly as before.

The frequency with which the periods occur is dependent on the number of pairs of poles in a machine, and on the speed at which the armature rotates. Fifty periods per second may be taken as a fair average, so that the armature of a machine having one pair of poles would have to make 3000 revolutions per minute. In order to reduce this speed the number of pairs of poles must be increased; thus, in a machine having four N and four S poles, arranged so that a pole of one kind is always between two poles of the opposite kind, the armature would have to make only 750 revolutions per minute.

Multiphase Alternating Current.—Having described how a single-phase alternating current is produced, we will now briefly consider the manner in which polyphase alternating currents are generated; that is, currents which at any given instance have two or more different phases.

To produce a two-phase current two sets of coils are required, wound on the armature of the generator, having their four ends attached to four collecting rings communicating with two separate circuits.

In Fig. 175, 1, (1) form one continuous coil, whose two ends are fastened to the two insulated rings 1 and (1) where the current is collected and allowed to pass into the circuit 1, (1). The coil 2, (2) has its two ends fastened to the two insulated rings 2 and (2), where the current is collected and allowed to pass into the circuit 2, (2).

The separate windings of the coil 1, (1) are separated from those corresponding in 2, (2) by an angle of 45 deg.,

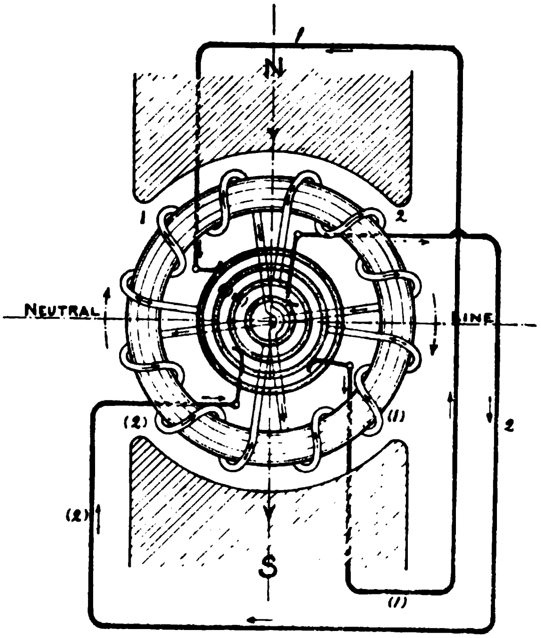

Fig. 175.

so that the current generated in 1, (1) is exactly a quarter of a period behind that generated in 2, (2). For if at a given instant while the armature is revolving a portion of the coil 1, (1) is exactly on the neutral line, the corresponding portion of the coil 2, (2) will be exactly on the vertical centre line opposite the N and S poles, and that portion of 1, (1) moves parallel with the lines of force passing from one pole to the other, cutting through none, and therefore generating no current, at the same instant as the portion of 2, (2) cuts through the lines of force at right angles, and the current generated is at its maximum pressure.

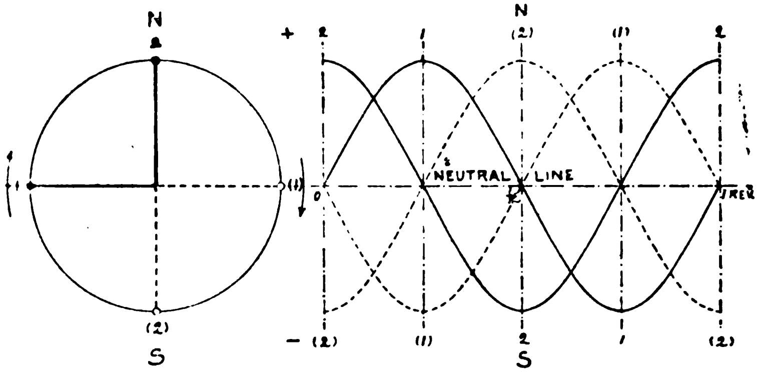

Fig. 176.

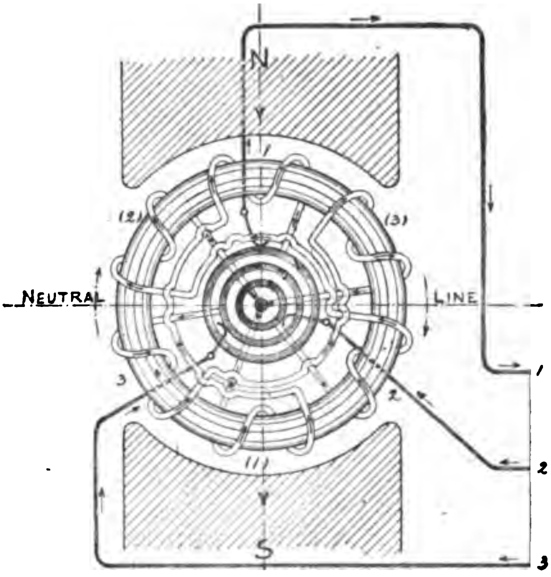

Fig. 177.

Fig. 176 represents the character of the currents generated by the two coils 1, (1) and 2, (2) during one revolution of the armature of a two-pole machine. It will be seen that there is a quarter of a period intervening between the two curves 1, (1) and 2, (2); also that at any given instant the currents have two different phases. This double current generated by one machine is called a two-phase or di-phase current.

Three-phase or tri-phase generators have the armature wound with three sets of coils, Fig. 177 showing the manner in which these are arranged in a machine having one pair of poles, and the curves in Fig. 178 represent the character

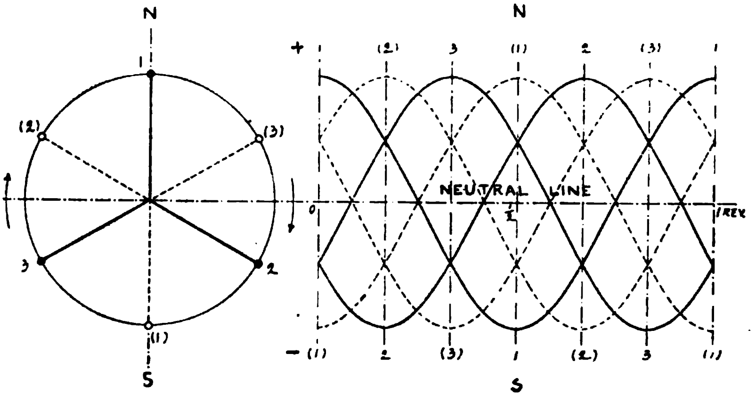

Fig. 178.

of the currents generated during one revolution of the armature.

Three-phase machines have almost entirely superseded the two-phase, for by using the same amount of metal in the construction of both, the three-phase machine generates about 11 per cent. more current than the two-phase, and motors worked by the former have a higher efficiency than those worked by the latter.

A reference to Fig. 178 will show that at any given instant the currents have three different phases, for while the two portions of the coil 1, (1) are exactly on the vertical line opposite to the N and S poles respectively with the current momentarily at its maximum positive pressure, the two portions of the coil 2, (2) are inclined at an angle of 60° to and approaching the S and N poles respectively with the current momentarily at half negative pressure, and the two portions of the coil 3, (3) are inclined at an angle of 60°, and receding from the N and S poles respectively with the current momentarily also at half negative pressure.

It may be as well here to point out that the current in any one coil at any given instant is exactly equal to the algebraic sum of the currents in the other two coils. Or we might say that at any moment there is in the three coils exactly the same amount of current flowing in a positive as in a negative direction; for if the current in one coil be momentarily at its maximum positive pressure, the currents in each of the other coils will be exactly alike, and at half negative pressure, the sum of which will be equal to the maximum in the one coil; or if the current in one coil be momentarily at zero, the currents in the other two will be

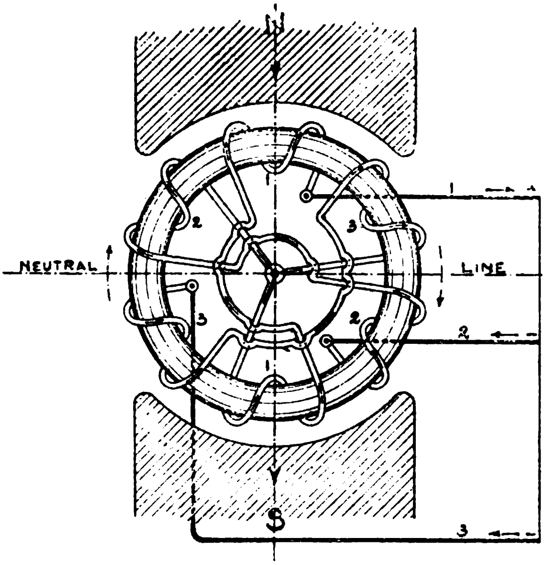

Fig. 179.

at exactly equal pressures, but one will be flowing in a positive and the other in a negative direction.

This may be clearly seen in Fig. 178, where the height of the curves above and below the neutral line indicate respectively the relative positive and negative pressures of the currents.

This fact is of very considerable importance, as it obviates the necessity for using six wires to form the circuit, for, by a suitable arrangement of the connections, three suffice, as shown in Fig. 177, or more clearly in Fig. 179.

It will be seen that the three wires forming the circuit communicate with one end of each of the three coils, the other three ends of which are connected together in the centre, where their currents neutralise each other.

By following the course of the two negative currents at half pressure, it will be seen that they enter the generator at coils 2 and 3 flowing through them, then through coils (2) and (3), and meet in the centre, where they combine and flow as one current into coil (1) and out of the generator again through coil 1 as a positive current at maximum pressure.

By connecting the ends of the coils of a two-phase generator in a suitable manner, three wires are also sufficient to form the circuit instead of four, so that in this respect two-phase and three-phase currents are alike, and possess no advantage over each other.

Continuous or Direct Currents.—The foregoing comprises a description of how single-phase, two-phase, and three phase alternating currents are generated; we have now to consider the manner in which a continuous or direct current is generated.

The essential difference between a continuous or direct-current generator and an alternator, whether single or polyphase, is that the former has a *commutator* while the latter has not.

The *commutator* is an apparatus for collecting separately the currents flowing in opposite directions generated by

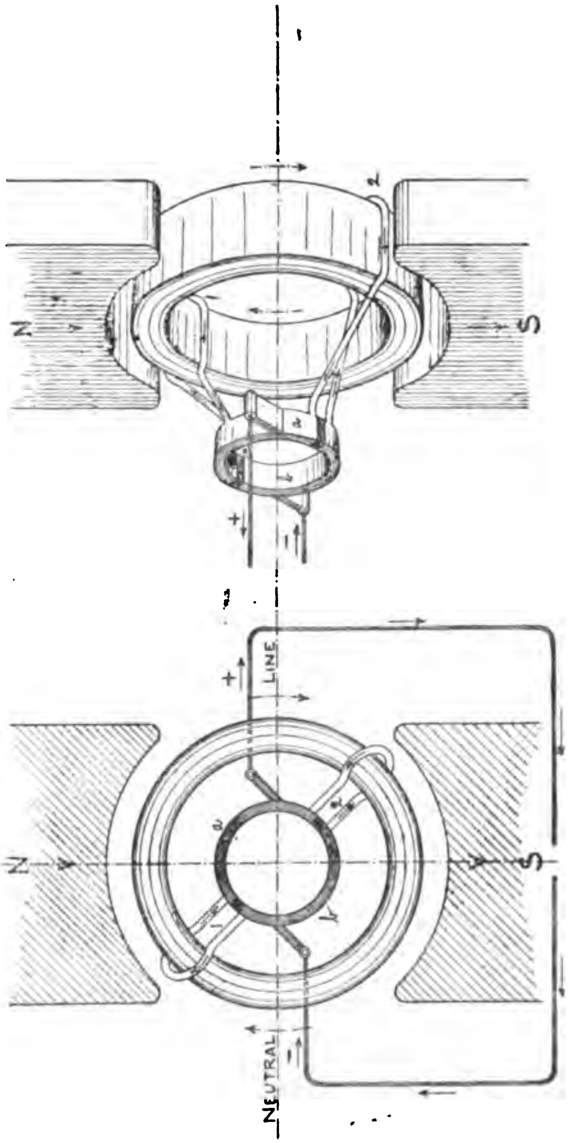

Fig. 180.

those coils which happen to be momentarily cutting through the lines of force at the N poles, and by those cutting through the lines of force at the S poles, and diverting these currents into two separate channels; whereby one of the brushes is always in communication with the ends of the coils which are of a high potential, and the other brush always with the ends which are of a low potential, so that the current flows through the circuit from one brush to the other continuously in the same direction, instead of flowing alternately in opposite directions from one to the other, as an alternating current does.

Fig. 180 shows a continuous-current generator with one N and one S pole and two coils wound on the armature core, whose four ends are connected to a collecting ring divided into two segments thoroughly insulated from one another, having two brushes pressing against its surface exactly on the neutral line which serve to connect the collecting ring with the circuit.

This divided collecting ring is the *commutator*, also known as the *collector*.

The brush on the right-hand side in the figure communicates with the ends of the armature coils which are of a high potential, being the source of the positive current, while the brush on the left-hand side communicates with the ends which are of a low potential—being the source of the negative current—and the current flows through the circuit from the positive to the negative brush. Assuming that the armature is being revolved in a clock-wise direction, as indicated by the arrows, at the moment when both the coils are on the neutral line there will be no current induced in them, and the brushes will be pressing against both segments of the commutator and against the insulating medium between them.

As the armature continues to rotate, coil 1 commences to cut through the lines of force at the N pole, and coil 2 those at the S pole, and the induced current in the two coils will flow in opposite directions with respect to the onlooker, as indicated by the arrows, whereby the ends of both coils in contact with the segment *a* are of a high potential, and the ones in contact with segment *b* are of a low potential, consequently the current will flow through the circuit from *a* to *b*.

On the completion of half a revolution both coils are again on the neutral line, with momentarily no current flowing through them, but next instant coil 1 commences to cut through the lines of force at the S pole, and coil 2 those at the N pole, so that the induced current flows through them in an opposite direction to what it did before, and the ends in contact with segment *b* are now of a high potential, while those in contact with segment *a* are now of a low potential.

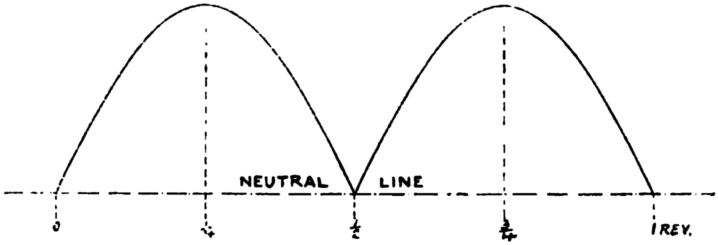

Fig. 181.

At the same instant as the current in the coils is reversed, however, whereby the potentials of the two segments are also reversed, the brushes pass from one segment to the other; so that the right-hand brush is still in contact with the segment of high potential and the left-hand brush still with the segment of low potential, the current flowing through the circuit in the same direction as before; or from segment *b* to segment *a*. The character of the current generated by one coil, or by two coils placed diametrically opposite to each other, as shown in Fig. 180, during one revolution of the armature of a machine having one pair of poles is represented by the curves in Fig. 181. It rises from zero to its maximum pressure as the coils travel from the neutral line to the vertical centre line, and the current falls again to zero on the completion of half a revolution, when the coils are once more on the neutral line. As the armature continues to rotate the current rises again to its maximum pressure, and finally falls to zero on the completion of one whole revolution.

The curve shows that the current flows always in one direction, for it rises on one side of the neutral line only.

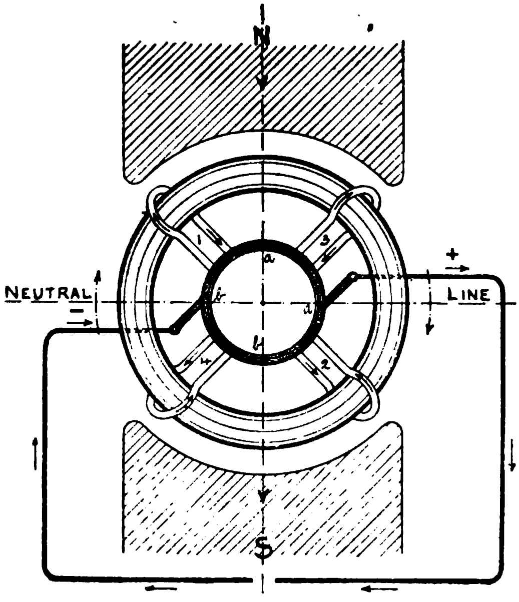

Fig. 182.

It also shows that the current has only one phase, and that it is not uniform, but flows in a series of waves, rising to its maximum pressure and dying away again twice during each revolution of the armature.

Uniform Continuous Currents.—Our next example, Fig. 182, shows the same machine as before, with two more coils on the armature core placed exactly diametrically opposite to each other and midway between the other two, thus making a total of four coils.

The commutator is now divided into four segments instead of two, to each of which are fastened the commencement of one coil and the end of the one following it as before, with two brushes to collect the current.

At a certain moment while the armature is revolving, coils 1 and 2 will be exactly on the neutral line, while coils 3 and 4 are on the vertical centre line opposite the N and S poles respectively, with each brush pressing between two segments of the commutator.

In coils 1 and 2 the induced current is momentarily at zero, while in coils 3 and 4 it is at its maximum pressure. After a quarter of a revolution coils 3 and 4 are on the neutral line, with the induced current at zero, while coils 1 and 2 are on the vertical centre line, with the induced current at its maximum pressure. It may be seen that now the current flowing into the circuit never sinks to zero, for when one pair of coils is on the neutral line the current from the other pair has a free passage through the commutator segments into the first, and thus the circuit is always supplied with current from one or the other pair of coils.

The character of the current generated by the two pairs of coils is represented by the curves shown in Fig. 183, from which it may be seen that as the current generated by coils 1 and 2 is rising from zero to its maximum pressure, the current generated by coils 3 and 4 is falling from its maximum pressure to zero. By adding the two currents together, we get the total current flowing through the brushes into the circuit at any instant, and this is represented by the dotted curve in the figure, showing that the current never falls to zero, but is at its minimum pressure when one pair of coils is on the neutral line, and at its maximum when both pairs of coils are at equal distances from the neutral, and from the vertical centre lines in the position shown in Fig. 182. The current generated by two pairs of coils is thus much less varying than that generated by one pair only, and the greater the number of coils and commutator segments, the more nearly the current approaches absolute uniformity.

Variation of Voltage.—The machine shown in Fig. 170 represents a continuous or direct-current generator, and the figure shows how the current generated is utilised for exciting the field magnets, by allowing a portion of it to flow through the coils of copper wires wound on their cores, thus making them electro-magnets.

By introducing resistances in front of the magnet coils which may be switched off or on, the amount of current flowing through them can be increased or decreased, thus exciting the magnets more or less powerfully, whereby a current of a higher or lower voltage, within certain limits, may be generated.

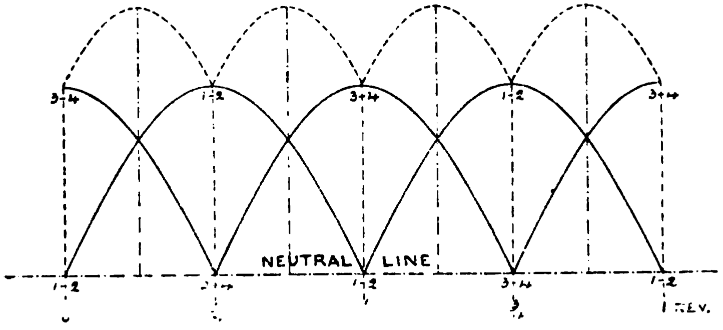

Fig. 183.

The field magnets have their cores usually made of steel, and they retain a portion of their magnetism when no current is flowing through the coils wound on them, so that a feeble current is induced in the coils of the armature when the machine is first set in motion. As this current flows through the coils of the field magnets it magnetises them still more, and a stronger current is then induced in the coils of the armature; thus the strength of the field magnets grows and the current generated grows too, in the same proportion, until a point is reached when the field magnets become saturated, as it were, with magnetism, and they attain their maximum strength. This method of exciting the field magnets cannot be adopted with alternating machines, for the alternating current is constantly changing, flowing alternately in opposite directions, so that it is useless for producing electro-magnets, as these would be constantly reversing their poles, and no current could be generated.

Alternating machines must have a separate continuous-current generator to excite their field magnets. This is a small generator, usually built as a part of the main machine, with its armature on the same spindle as the armature for generating the alternating current.

In our next chapter we shall deal with what is fast becoming an influential part of the electrical industry, viz., the construction of the various types of electro-motors. The great increase in the use of this power for driving machinery and other purposes, gives this section of our subject a special interest.

CHAPTER XXII.

ELECTRO-MOTORS.

THE different types of electric generators and the character of the currents they generate having now been described, we have still to consider how the power expended in the generation of the current by forcibly revolving the armature of the generator may be regained at some distant place, by conducting the current thence along copper wires, and causing it to flow through a motor, whereby its armature is set in motion with almost the same force as that applied to the armature of the generator to produce the current, the loss of power being due mainly to the resistance of the conductors opposing the flow of the current, but also to several other causes, such as the friction of the armature spindles on their bearings, &c. Continuous-current motors are constructed on exactly the same lines as generators.

In a generator the coils of the armature cut through the lines of force in a magnetic field, causing magnetic lines of force to travel round the coils in opposition to those of the magnetic field, and a current of electricity to flow through them.

In a motor a current of electricity magnetises the field magnets, thus producing a magnetic field in which the armature is suspended, and a current of electricity at the same time flows through the coils of the armature, causing magnetic lines of force to travel round them, which, by setting themselves in opposition to those of the magnetic field, impart rotation to the armature.

Fig. 184 shows the manner in which the current from the generator is made to flow through the motor by connecting the two brushes of the former with those of the latter.

In the motor as well as in the generator a portion of the current flows through the coils of the field magnets, while the rest flows through those of the armature.

Since by passing a current of electricity through a conductor magnetic lines of force are made to circle round it in either direction, according to which end the current is made to enter the conductor, it is obvious that if a conductor is suspended in a constant magnetic field and a current be sent through it, entering first at one end, then at the other, the lines of force, by circling round the conductor, first in one direction, then in another, will cause it to move in opposite directions. By this means the armature of a motor can be made to rotate in either direction and reversed at will, the manner in which this is effected being shown in the diagram.

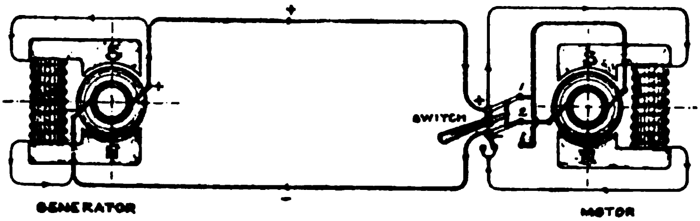

Fig. 184.

By means of a double-pole switch connected with the positive and negative brushes of the generator, the brushes of the motor can be differently connected with those of the generator, so that either becomes positive or negative, and the current is thereby made to flow through the coils of the armature in either direction.

The current flowing through the coils of the field magnets may not be reversed, however, as the poles must always remain constant.

Single-phase alternating-current motors are also constructed on exactly the same lines as the generator; that is, the field magnets are excited separately by a continuous current flowing through their coils, while the armature is supplied with alternating current from the generator. (See Fig. 185.)

It is essential in these machines that the motor should run at exactly the same speed as the generator if both machines have an equal number of poles, and faster or slower if the motor has fewer or more poles than the generator, and in proportion to the number of poles in both machines. The poles of the field magnets remain constant, whereas the current in the coils of the armature is constantly changing.

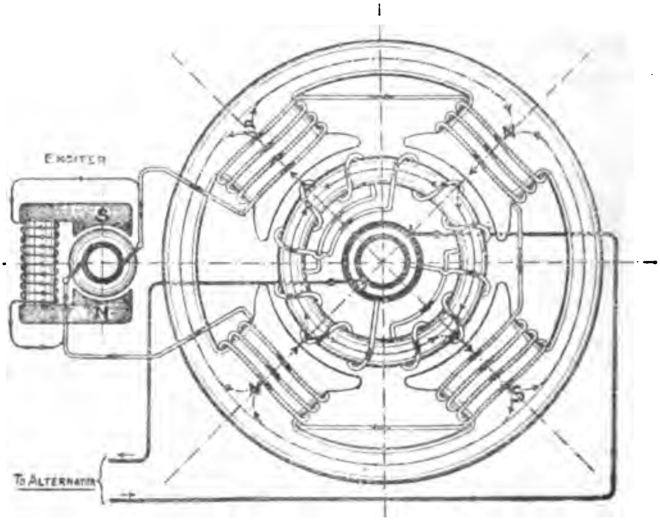

Fig. 185.

At a certain moment one set of coils is opposite the N poles, and the other set opposite the S poles, with the current flowing through them in opposite directions, so that they both tend to impart rotation to the armature in one direction only.

Next instant the current in the coils is reversed, and in order that the rotation of the armature may continue in the same direction the coils must have traversed the space which divides a N pole from a S pole, so that those coils which were formerly opposite the N poles are now opposite the S poles, and those coils which were opposite the S poles are now opposite the N poles. That is to say, a coil being opposite a N pole with the current flowing momentarily through it towards the onlooker tends to impart a clockwise rotation to the armature. Next instant the current flows away from the onlooker, and if the coil be still opposite a N pole it will drive the armature back again, or in an opposite direction. As the current changes, therefore, the coil must have travelled as far as the neighbouring S pole, so that the armature may continue rotating in the same direction, otherwise it will simply oscillate backwards and forwards.

In order that the motor may work, the armature must traverse the space dividing a N from a S pole with the same frequency as the current changes from positive to negative. To start the motor, the armature must be first revolved by hand, or by any other means, until the necessary speed is attained, when it will continue revolving as long as it is supplied with current, but it is liable to stop if a heavy load is suddenly put on.

In the case of small motors a portion of the alternating current may be converted into a pulsating continuous current by means of a commutator on the armature spindle, with which the magnets can be sufficiently excited.

The larger motors are usually built with a small continuous-current generator on the armature spindle for exciting the field magnet. To start these motors the small generator may be made to work as a motor by supplying it with continuous current from an accumulator until the requisite speed is imparted to the armature, when the accumulator may be switched off, and the motor then generates its own continuous current for exciting the field magnets, with which, too, the accumulator may be recharged. Two and three-phase alternating-current motors may also be worked on this principle, and they have the advantage over single-phase motors in being self-starting, at least when unloaded.

In recent years single and polyphase alternating-current motors have been devised and constructed which work, although not well, on the same principle as continuous-current motors; that is to say, the alternating current flows through the coils of the field magnets and magnetises them at the same time as through the coils of the armature, the use of a commutator being thus, of course, necessary.

The cores of the field magnets must be specially constructed, having alternate layers of very thin sheets of special soft iron and thin insulating material, so as to obviate as much as possible the loss of power that magnetising them alternately in opposite directions entails; for electro-magnets with cores of very soft iron retain only a very small portion of their magnetism, or none at all, after the current ceases to flow through their coils, whereas those having steel cores retain a considerable portion of their magnetism.

These motors are self-starting under full load, and they can be run at any speed, independently of that at which the generator runs.

The disadvantage of having a commutator on any class of generator or motor lies in the fact that as a commutator segment crosses the neutral line where the brushes press against the commutator, opposing currents suddenly meet, which cause sparks to form between the segment and the brush, thereby injuring the surface of the commutator.

The liability to sparking is greatest on those motors which run in both directions; but it can be kept within practical limits by working them with a current of not more than about 500 volts pressure, and by the use of thick carbon brushes adjusted to press radially against the surface of the commutator.

The modern alternating-current motors, so-called *induction motors*, are worked on an entirely different principle from those hitherto described, having only the field magnets excited, the armature being altogether disconnected from the generator.

These motors have a very high efficiency, and are self-starting under full load. They have no commutator, but simple collecting rings on the armature spindle become necessary if the speed requires regulating, otherwise they can be entirely dispensed with.

Induction Motors.—If we take two semicircular pieces of iron, and by winding insulated copper wire round them in the manner shown in Fig. 186, and passing a current of electricity through the wire we produce two electro-magnets, having the two N poles opposite to each other, and likewise the two S poles opposite to each other; and the lines of force will have a tendency to traverse the air space intervening between the two poles, as shown by the dotted lines and arrow heads, thus producing a magnetic field between the two poles.

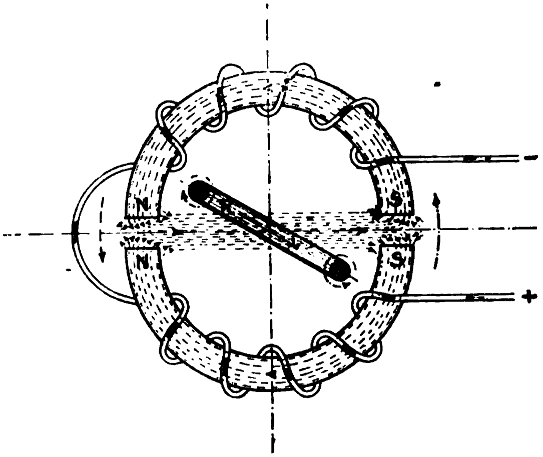

Fig. 186

If we join these two semicircular magnets together the poles still remain the same, and the lines of force will take the same course from one to the other as before, so that the magnetic field remains unaltered.

If we now suspend a ring of copper or other conducting metal R, so that it is free to revolve inside the magnet ring, and revolve the latter, so that the lines of force passing from the N to the S poles are cut through by the wire ring, magnetic lines of force will circle round the wire in such a direction that they resist the rotation of the magnet ring, and because the former is free to revolve, the latter drags it round with it and causes it to rotate, but at a slower speed, as otherwise no lines of force would be cut through, and magnetic lines of force would cease to circle round the wire.

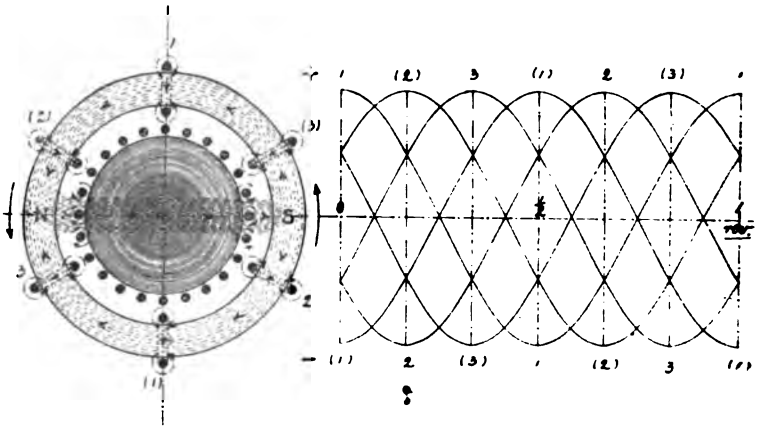

Fig. 167

This explains briefly the principle on which induction motors are worked, but although in these motors a rotating magnetic field is necessary, the magnets themselves do not rotate, for with two or more alternating currents of different phase a rotating magnetic field can be produced with stationary field magnets.

A three-phase induction motor has field magnets consisting of a laminated iron ring wound with three sets of coils, in the same manner as the armature of the generator shown in Figs. 177 and 179, each set of coils on the motor being connected directly with the corresponding ones on the generator. Fig. 187 shows the armature and field magnets of a motor in position, with the coils of both shown in section, the former, to avoid complicating the description, being shown as if each were wound only once round the core, instead of a great many number of times, as is the case in the actual machines; and the adjoining curves represent the character of the currents flowing through each coil at any moment during one revolution of the armature of the generator.

At a certain moment the current in coil 1, (1) is at its maximum pressure, while in coils (2), 2 and (3), 3 the currents are at half pressure; in coil (2), 2 growing and in coil (3), 3 diminishing. The currents flowing through the coils above the horizontal centre line are momentarily positive, while those flowing through the coils below are momentarily negative, and the lines of force travel through the iron core of the field magnets in the manner shown by the dotted lines and arrow heads, thereby producing a N pole on the left-hand side, and a S pole on the right-hand side.

As the armature of the generator continues to revolve, the currents flowing through the coils alter, so that a moment afterwards it has attained its maximum pressure in coil (2) 2, next moment in coil (3) 3, and after half a revolution in coil 1 (1) again, but reversed; so that those coils which are above the horizontal centre line have now a negative current flowing through them, and those below a positive current. Thus the current attains its maximum positive and negative pressure in each pair of coils, placed diametrically opposite to each other in succession, so that the N and S poles are constantly assuming a different position and travel right round the ring, whereby the magnetic field rotates just as if the magnetic ring itself were being revolved, and with the same speed as the armature of the generator which supplies the current.

The armature consists of a cylindrical laminated iron core, having a spindle on which it revolves, and a number of insulated copper wires or bars arranged on its outer surface, parallel with each other and with the spindle. These wires, or bars, are connected together at both ends on the face of the core by metal rings or discs, one on each side, so that the induced current can flow freely from one wire to another; but they have no connection with the generator whatever, the current flowing through them being generated as the lines of force from the rotating magnetic field are cut through by the wires, thus causing opposing lines of force to circle round them.

Instead of connecting all the wires together so that the induced current can flow uninterruptedly from one to the other, they can be connected in groups to insulated metal rings on the armature spindle, having brushes to collect the current connected with resistances through which the current is compelled to flow, whereby a portion of it is destroyed, and thus less current flows through the wires and fewer lines of force circle round them.

By means of a switch any number of resistances can be switched on, or all can be disconnected, allowing the full current to flow through the wires, whereby the speed of the armature can be regulated, this being especially necessary while starting and stopping with a heavy load, or, in fact, whenever starting and stopping gradually is desirable.

Two-phase induction motors are worked in exactly the same manner, only that two sets of coils are wound on the field magnets instead of three, the current being supplied by a two-phase generator.

Lately induction motors have been made to work with single-phase current by splitting up the current into two portions, and retarding one portion so that it enters the motor a quarter of a period behind the other, thereby producing a second phase artificially while the motor is being started and until it has attained its full speed, when it concontinues working with the single-phase current in its ordinary state, oscillating backwards and forwards between the two portions of the coils placed diametrically opposite to each other. These machines are not nearly so efficient as the two and three-phase, however, and they are liable to stop whenever a heavy load is suddenly put on.

CHAPTER XXIII.

TRANSFORMERS.

We have already mentioned that the electric unit of power, the volt-ampère or watt, equal to about $\frac{1}{746}$ of a horse-power, is the product of one volt and one ampère. Thus the power of a current of 100 ampères at 10 volts pressure is one kilowatt, equal to about $1\frac{1}{3}$ horse-power, and the power of a current of 10 ampères at 100 volts pressure is also one kilowatt.

The sectional area of the wire along which a current is conducted is dependent on the ampères of current; thus to conduct a current of 100 ampères a copper wire having an area of about 50 square millimetres is required; whereas to conduct a current of 10 ampères an area of about $2\frac{1}{2}$ square millimetres is sufficient, quite independently of the voltage of the current.

The power which can be transmitted electrically by means of a wire having a given area varies, therefore, with the pressure or voltage of the current; thus along a copper wire having an area of 50 square millimetres, equivalent to about a quarter of an inch diameter, one kilowatt, equal to $1\frac{1}{3}$ horse-power, can be transmitted with a current at 10 volts pressure; or 10 kilowatts, equal to $13\frac{1}{3}$ horse-power, with a current at 100 volts pressure; and 100 kilowatts, equal to $133\frac{1}{3}$ horse-power, with a current at 1000 volts pressure.

These figures are only approximate, and meant to show the relation that exists between the powers that can be transmitted at different voltages, as no general rule can be laid down for determining the size of a wire to conduct a given current; since, owing to internal resistance, the wire becomes more or less heated, with a consequent loss of current.

By increasing the sectional area of a wire its conductivity is increased, and there will be less current absorbed in the shape of heat.

It is obvious that there will be a greater loss in conducting a current along a very long wire than along a very short one, and the loss is proportional to the length of the wire; so that if conducting a current along a very short wire results in a certain percentage of loss, whereby the wire becomes appreciably warm, by increasing the length without increasing the sectional area of the wire a point will eventually be reached where the whole of the current is absorbed in the shape of heat, and none is available for other purposes.

The main point to be considered in determining the size of the wire where a current has to be conducted a very long distance, is the capital which must be spent on the conducting wire, and to what extent this may be increased to minimise the loss of current in the wire by increasing its area, so that the money representing the extra current obtained thereby covers the interest on the extra outlay. This is, of course, a very complicated matter, and requires very deep and careful calculation.

From the foregoing it will be clearly understood that to conduct a current of electricity to any considerable distance economically a high voltage must be employed, so as to reduce the quantity of copper in the wires as much as possible.

On the Continent and in the United States of America currents of as high a voltage as 10,000 or 12,000 are by no means infrequently used for transmitting power electrically to very great distances, and there are instances where even 30,000 volts are attained. There are isolated instances of continuous currents being employed for transmitting power to very great distances at very high voltages reaching up to 15,000, but it is impossible with one machine to generate a continuous current of such a high voltage as this. In such cases several generators must be used connected in series, so that the current generated by the first passes on to the second, and from this to the third, and so on, the voltage being increased as the current passes through each successive machine, but the difference of potential between the positive and negative terminals of any one machine may not exceed about 2000. And in the same way at the receiving station, where the current is conducted, it drives a number of motors connected in series.

In Switzerland, where a continuous current of 14,400 volts is generated at Combe-Garrot and conducted a distance of twenty kilometres to Chaux de Fonds, nine generators are used, connected in series, so that the difference of potential between the positive and negative terminals of any one generator does not exceed 1800 volts, and at the receiving station the motors work with a maximum difference of potential of 600 volts between each of their positive and negative terminals.

It is possible, although difficult, to construct good dynamos to generate a continuous current of 2000 to 3000 volts, or even more, but the difficulty of effectively insulating these machines and constructing them so that no sparks are formed at the commutator is so great, and involves a so much greater cost, that such high voltages cannot be generated economically; nor is this of very great importance in these days when alternating currents can be generated so easily to serve the same purpose, namely, to transmit power from one place to another at a very great distance away, and when alternating machines have reached such a high state of perfection.

The employment of such high voltages is, of course, not without some considerable danger connected with it which must be carefully guarded against, as a shock might result in instant loss of life or permanent disablement of a person, and the insulating material surrounding wires in contact with metals or other conducting substances must be very perfect, as it is otherwise very liable to be punctured by the current in its endeavours to force itself a way through and escape.

For general motive purposes or for driving motors which require to be frequently reversed, a continuous current of from 100 to 500 volts is most frequently and satisfactorily employed.

Incandescent lamps are now made giving satisfactory results when used with a current at 220 or even 250 volts but the life of the lamps is shortened to a prohibitive extent by raising the voltage beyond this. The most common voltage for lighting with incandescent lamps is 100, and it is only within the last few years that manufacturers have been able to put on the market a durable and efficient lamp for use on 220-volt circuits. Alternating currents can be generated at a much higher voltage and with greater ease than continuous currents, for the sensitive part of the continuous-current generator, namely, the commutator, does not exist in the alternating machines, as these have only simple slip rings and brushes for collecting the current.

There is also another reason why alternating currents can be generated advantageously at a very high voltage, whereas continuous currents cannot. A high - voltage current is only advantageous in transmitting power between two distant places on account of the saving that can be effected in the conducting wires, but for use in the ordinary way for motive purposes it is extremely inconvenient, as well as dangerous, and for lighting purposes altogether impracticable. With alternating currents the voltage can be raised or lowered with the greatest ease by means of transformers which have no rotating parts, consequently require no attention and have also a very high efficiency; that is to say, there is only a very slight loss of power in transforming an alternating current from a high to a low voltage, or *vice versâ.*

A current is generated at say, 2000 volts, and by means of transformers this voltage is raised to, say, 30,000, so as to economise in the wires necessary to conduct the current to a receiving station at a far-distant town, where it is to be utilised for lighting purposes. At the receiving station the current of 30,000 volts is transformed into one of 2000 volts, and in that state conducted to the different houses, at each of which it is again transformed to 100 volts, so as to be suitable for lighting with incandescent lamps. In this way a great saving is effected in the conducting wires, and inside the town the voltage is kept down to within reasonable and convenient limits.

Transformers for continuous currents are combinations of a dynamo and a motor, and have consequently the disadvantages of both, besides being comparatively expensive machines. The motor receives the current at a high or low voltage and drives the dynamo which is wound to generate a current of the required voltage.

For example, a 100-kilowatt machine generates a continuous current of say, 100 ampères at 1000 volts pressure, which must be utilised for lighting purposes a considerable distance away.

This current drives the motor-dynamo which transforms it into one of nearly 1000 ampères at 100 volts pressure, there being some loss of power due to the internal resistance of the machine itself. Rotary transformers consist sometimes of two separate machines, a dynamo and a motor, mounted on one base plate and firmly coupled together; but usually a special machine is used, furnished with a double armature having two separate sets of coils with two commutators mounted on one spindle, one half working as a motor and causing the spindle to rotate, while the other half works as a dynamo and generates a current. These machines can also be made for driving with an alternating current and generating continuous, or for driving with a continuous current and generating alternating.

For altering the voltage of alternating currents stationary transformers are used, which are altogether unlike the rotary transformer for continuous currents, having no working parts whatever; consequently they have a very high efficiency and require no more attention than the conducting wires.

In its simplest form this class of transformer consists of an iron ring having a primary and a secondary coil of insulated copper wire wound round it, in the manner shown in Fig. 188. The two ends of the primary coil *a* are connected with the positive and negative terminals of a generator so that a current passes through the wire forming the coil, causing lines of force to circle round it which travel through the iron ring and magnetise it.

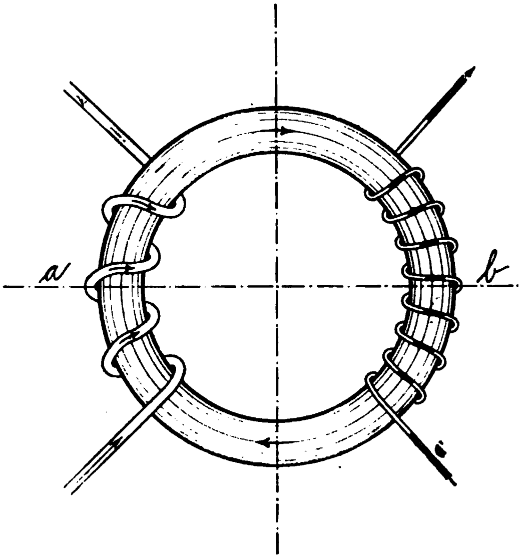

Fig. 188.

As the magnetic lines of force traverse the portion of the iron ring where the secondary coil *b* is wound they are intercepted and cut through by the wires, thus causing opposing lines of force to circle round them, and a current of electricity to flow through the secondary coil *b*.

Coil *a* receives its current direct from the generator, and is therefore primary, whereas the secondary coil *b* receives its current by induction.

If both coils consist of an equal number of turns round the iron ring, the same number of lines of force which circle round the wire forming the primary coil, and which magnetise the iron, are cut through in the same time by the wire forming the secondary coil, and the induced or secondary current will be theoretically exactly the same as the primary.

If the secondary coil has more turns than the primary, the voltage of the secondary current will be higher than the primary; for a greater number of lines of force will be cut through in a given time by the secondary coil than are emitted from the primary coil; but the ampères of the secondary current will be less than the ampères of the primary, the product of the volts and the ampères or the watts being theoretically the same in both the primary and secondary currents. If, on the other hand, the primary coil has a greater number of turns than the secondary, the voltage of the secondary current will be lower than the voltage of the primary, but the ampères will be increased.

In the figure the coil *a* consists of four turns and *b* consists of eight. Assuming that *a* is the primary coil having a current of 20 ampères at 100 volts pressure flowing through it, the current induced in coil *b* will be nearly 10 ampères at 200 volts pressure. There will be some loss of power due to the resistance to the electric current in the coils and to the magnetic lines of force in the iron core, and some also due to the fact that not all the lines of force are utilised for inducing a current in the secondary coil, as some manage to escape through the air instead of through the iron core and past the secondary coil.

Transformers of this class are merely practical applications in their simplest possible form of the principles enumerated in Lenz's law. That is to say, an alternating current flowing through a coil of insulated copper wire surrounding a piece of iron constantly magnetises it alternately in opposite directions, and causes a constant change to take place in a magnetic field in relation to an electrical conductor placed within its influence, namely, the secondary coil, and thereby produces by induction an alternating electric current in the secondary coil.

It is clear that if a continuous current were to flow through the primary coil an alteration in the magnetic field in relation to the electrical conductor forming the secondary coil would only take place at the instant when the current is turned on or off, thereby momentarily inducing a feeble current in the secondary coil. These transformers, therefore, can only be used with alternating currents.

Properly constructed transformers for alternating currents of from 5 to 200 kilowatts have an efficiency of about 93 to 98 per cent., the larger ones having a higher efficiency than the smaller. That is, about 2 to 7 per cent. of the current is lost in the process of transformation, through the internal resistance of the machine, when used with the full current for which it is constructed, but when used with a weaker current the percentage of loss is considerably greater.

CHAPTER XXIV.

MEASUREMENT OF CURRENT.

HAVING briefly described the principle of the modern electric generators, motors, and transformers, we will proceed to define more clearly some of the units in which the power of a current is expressed, and which have been frequently mentioned in the foregoing chapters, as well as to describe what relation they bear to one another, and, as far as possible in a simple manner, how they are measured and what their equivalents are in measures with which all are familiar.

The Ampère, the unit in which the quantity of electricity conveyed in a current is expressed, is that quantity flowing for one second of time through a solution of nitrate of silver in water which deposits 1·12 mgr. of silver. It may also be measured by the power of the magnetic lines of force which it is capable of creating when conducted along a coil of wire; and on this property is based the construction of the modern ampère-meter, or ammeter.

The Ohm, the unit in which resistance to the flow of a current of electricity is expressed, equivalent to friction in mechanics, is the resistance of a column of mercury having a sectional area of one square millimetre and a length of 1063 mm., at a temperature of 0° Cent. That is to say, if a current of one ampère with an electromotive force of one volt is applied to the end of the column of mercury, the resistance is just sufficient to absorb the whole of the current by converting it into heat so that none is available at the other end.

The Volt, the unit in which the electromotive force caused by a difference of electric potential in a conductor is expressed, or, as it is sometimes called, the pressure of a current, is that electromotive force which produces a current of one ampère in a conductor whose resistance is one ohm

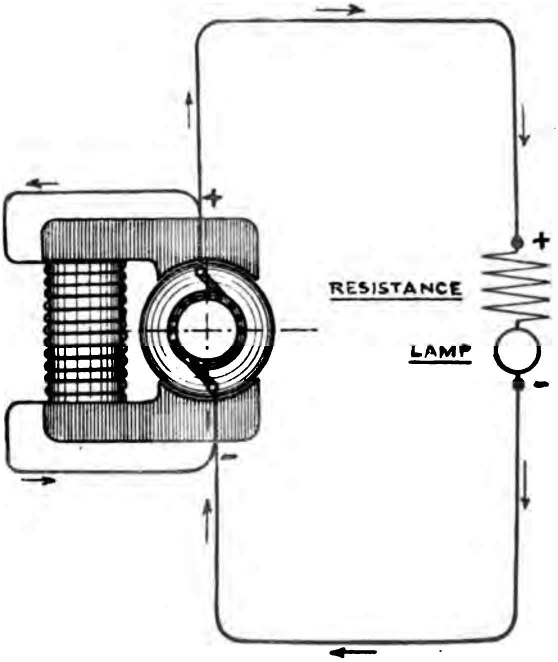

Fig. 183.

The law discovered by Dr. Ohm, and called after him Ohm's law, may be expressed as follows :—

The electromotive force necessary to cause a current of electricity to flow from one point to another in a conductor, measured in volts, is equal to the quantity of the electricity measured in ampères multiplied by the resistance of the conductor measured in ohms. Thus 1 volt = 1 ampère × 1 ohm, or 1 ampère = 1 volt ÷ 1 ohm. To illustrate more clearly the relation that exists between these three units we will again refer to our illustration of the bent tube filled with air—see Fig. 164, page 332.

When the tap is turned on full so that the air can pass freely from one side of the tube to the other, if the piston is moved there is very little resistance to the movement, and very little pressure need be applied to cause it to move. If we now half close the tap so that the opening is only half as large as it was when turned on full, the resistance to the passage of the air is twice as great as it was before, consequently twice the pressure must be applied to the piston to move it the same distance in the same time.

When the tap was turned on full, if a pressure of 1 lb. applied to the handle of the piston was sufficient to move it 1ft. in one second, assuming that the area of the piston is one square inch 12 cubic inches of air will pass through the tap in one second; and when the opening in the tap is reduced by one-half so that twice the resistance is offered to the passage of the air, twice the pressure, or 2 lb., must be applied to the handle of the piston to send the same quantity of air, 12 cubic inches, through the tap in one second. Or if 1 lb. pressure is applied, only 6 cubic inches of air will pass through the tap in one second. The ampère, the ohm, and the volt bear the same relation to one another when a current of electricity flows through a conductor that the quantity of air, the resistance offered to its passage dependent on the size of the hole in the tap, and the pressure applied to it by means of the piston, bear to one another in our illustration.

Let it be assumed that in a circuit supplied with a constant current from a generator having a difference of potential of 100 volts between its positive and negative terminals, we wish to connect some arc lamps constructed to work with a difference of potential of 40 volts between each of their positive and negative terminals, the quantity of current required by each to give the requisite candle-power being 10 ampères.

Now, since according to Ohm's law, ampères = volts ÷

ohms, then ohms = volts ÷ ampères, and in our example we have 40 volts and 10 ampères, so that the resistance of each lamp will be 40 ÷ 10 = 4 ohms.

To connect a single 40-volt 10-ampère lamp to the 100-volt circuit, we should have to increase the resistance of the lamp to 10 ohms by adding to it an extra resistance of 6 ohms, so that 10 ohms × 10 ampères = 100 volts, thus

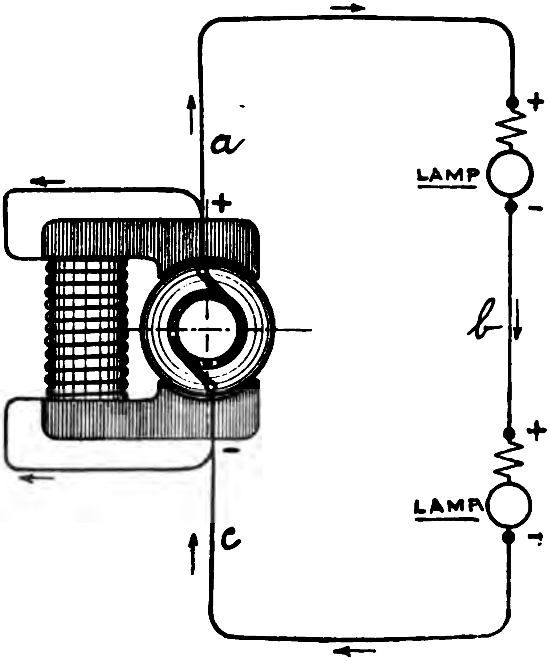

Fig. 190

involving a loss of 60 per cent. of the electrical energy—see Fig. 189. We can, however, double the efficiency of the installation by connecting two lamps in series, that is, one behind the other, so that the same current flows through each lamp in succession, but the arrangement necessitates always having both lamps alight simultaneously. In this way the resistance of the lamps is increased to 8 ohms, and it will be necessary to add an extra resistance of only 1 ohm to each lamp to give the requisite voltage. Fig. 190 shows the arrangement.

It may be mentioned here that it is always advisable or even necessary to add some extra resistance to each arc lamp, as this is of assistance to the mechanism for feeding the carbons in producing a steady light.

Since the difference of potential between *a* and *c* in Fig. 190 is 100 volts, and the resistance 10 ohms, a current of 10 ampères will flow from *a* to *c*, and the resistance between *a* and *b* being only 5 ohms, the difference of potential between *a* and *b* is 50 volts, and between *b* and *c* also 50 volts, making a total of 100 volts between *a* and *c* with a constant current of 10 ampères flowing from *a* to *c*.

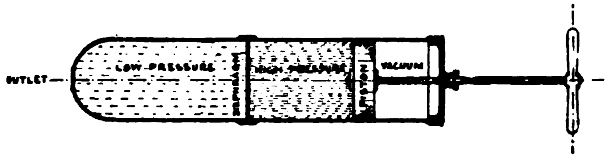

Fig. 191.

As a current of 10 ampères is required for each lamp at a pressure of only 40 volts, the resistance of each lamp being 4 ohms, the extra resistance of 1 ohm is required only to reduce the voltage by absorbing a portion of the current.

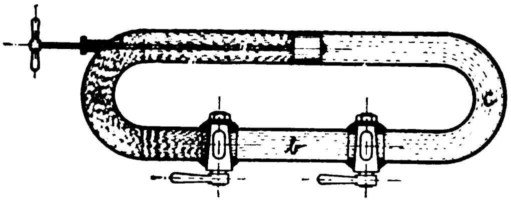

Fig. 192.

The conducting wire may be compared to a tube of uniform bore throughout but with a diaphragm in the centre, having a piston on one side of it and an outlet hole on the other side—Fig. 191. If the air on one side of the tube is compressed by means of the piston, the pressure on the piston side of the diaphragm will be greater than the pressure on the other side, and the difference of pressure will depend on the size of the opening in the diaphragm and on the outlet hole; for if the diaphragm is entirely closed there will be a certain pressure on the side where the piston is, but on the other side there will be none, and if the diaphragm is entirely removed the pressure will be uniform throughout the tube, and any intermediate difference of pressure will depend on the size of the opening in the diaphragm. The piston in this case may be compared with the generator, the outlet hole with the resistance due to the arc lamp and the diaphragm with the intermediate resistance to regulate the pressure of the current flowing through the lamp.

Again referring to our illustration of the bent tube, this time having two taps instead of one, as shown in Fig. 192, a movement of the piston in the direction indicated by the arrow compresses the air at *a* and produces a partial vacuum at *c*, and if the air is compressed to 1 lb. per square inch at *a* the vacuum at *c* will have a pressure of 1 lb. per square inch also, but negative to the pressure at *a*, so that the difference of pressure between *a* and *c* will be 2 lb. per square inch.

Assuming that both the taps are closed, the condition of the air at *b* is the same as that of the air outside surrounding the tube, and in respect to the air inside the tube at *a* and *c* neutral. The difference of pressure between *a* and *b* will therefore be 1 lb., and between *b* and *c* 1 lb. also, making a total of 2 lb. between *a* and *c*. If the openings in both taps are alike they both offer the same amount of resistance to the passage of the air, and if they are both opened simultaneously the air will rush from *a* into *b* and from *b* into *c* with a uniform velocity without affecting the condition of the air at *b* which still remains neutral, assuming, of course, that the initial pressure on the piston is kept up. This is obvious, for if the air at *b* were compressed to the same degree as at *a* no air would pass from *a* to *b*, and likewise if rarified to the same degree as at *c* no air would pass from *b* to *c*.

This serves to illustrate the condition of the electric current at different points in a circuit when lamps or motors are connected in series—see Fig. 190—and also the nature of the current at the positive and negative terminals of a generator; the one being comparable to the outward pressure when air is compressed in a tube, and the other to the inward pressure when a vacuum is formed in a tube.

The power of a current of electricity is the product of the current as measured in ampères, and the difference of potential or pressure as measured in volts between any two points in a circuit intercepted by a resistance, which may be a motor or a lamp, or even a more or less imperfect conductor; and at any given instant this power is theoretically equal to the power which a motor or any other resistance exerts at the same instant in doing a certain amount of work.

For instance, an electric generator connected with a circuit for supplying a motor with current supplies only just sufficient for the work which the motor has to do, and when the load is taken off the motor the current is only sufficient to overcome the resistance to the flow of the current in the conductors and the resistance to the rotation of the armature caused by the air and by the friction in the bearings of the armature spindle; and just as in our illustration we showed that the pressure of the air on one side of the tap is a positive pressure when the piston is moved, and on the other side a negative pressure, so the pressure or potential of the current in the circuit is positive on one side of the motor or other resistance, and on the other side negative. The difference between the pressure of the air on each side of the tap is that available for work, and represents the potential of the current.

As there is no loss of air in the air pump when the air passes from one side of the tap to the other but only a transmission of power by the aid of the air molecules, so there is no loss of current when this is used for driving a motor or for producing a light but only a reduction of potential in doing work.

The action is merely a change of condition instantly transmitted along a metal conductor. The current carries the initial motive power, comparable to air under pressure, to the point at which the work has to be done, which may be the vibration of carbon molecules to produce a light, or the creation of magnetic lines of force to drive a machine, or the production of heat in overcoming the resistance of an imperfect conductor; and for comparison it may be said that, like the air molecules in our air pump, after doing its work it passes on at a lower pressure to the minus or negative wire, there to equalise the potential. As a continuous working pump would gather up the air molecules and again compress them, so the dynamo continually creates a condition of *difference of potential* and thus supplies a constant current of that force which we term electricity.

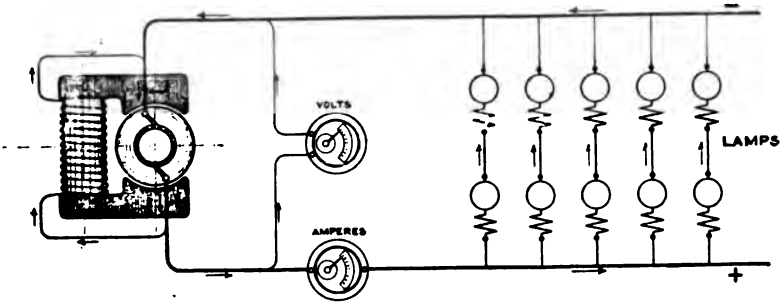

Fig. 193.

In order to measure a current of electricity two instruments must be used, namely, the *ammeter* for measuring the quantity of electricity conveyed in the current, and the *voltmeter* for measuring the potential or pressure of the current.

These two instruments are connected up to the circuit in the manner shown in the diagram, Fig. 193.

There are many other instruments in use, such as *voltameters*, for measuring the actual quantity of electricity supplied to consumers, registering this like gas by a gasmeter; *wattmeters*, for measuring electrical power, and registering this like a voltameter, but—unlike the voltameter—taking both the volts and the ampères into consideration; *ohmmeters*, for measuring the resistance of conductors, &c. &c. But it is beyond the scope of these articles to enter into a description of these, consequently we will restrict ourselves to describing very briefly the voltmeter and the ammeter only, and the manner in which these two instruments are connected up to the circuit, as this is of importance in order to more fully elucidate the action of the electric current in a circuit.

The ammeter is connected directly in the circuit so that the whole of the current used for the lamps or motors has to pass through it, and consists of a needle pivoted over a graduated scale in such a manner that the current passing through a *short thick* coil of wire of low resistance is utilised for deflecting the needle by the magnetic lines of force which it produces.

The voltmeter, on the other hand, is not connected directly in the circuit but it is connected to it at two points, one on the positive and one on the negative wire, by a separate wire, and measures the difference of potential between those two points, usually close to the terminals of the dynamo. The voltmeter is often exactly similar in construction to the ammeter, with the difference that a very *long thin* coil of wire of high resistance—often many thousand ohms—is used instead of a short thick coil. In the case of Cardew's voltmeter, however, the deflection of the needle is brought about by the expansion of a long thin platinum wire caused by the heat produced as the current passes through it; but in all voltmeters the current has a very high resistance to overcome so that only a very minute quantity passes through the instrument.

It is of inestimable value to electrical engineers that a circuit may be divided at any point and joined together again by any number of conductors, and the current will not, as might be supposed, flow along the line of least resistance only, but it will flow along each conductor exactly in proportion to its conductance; that is, inversely in proportion to its resistance. If the resistances of two conductors be R and r, their conductances will be reciprocals of these values, or $\frac{1}{R}$ and $\frac{1}{r}$ respectively; their joint conductance, or the sum of their separate conductances, $\frac{1}{R} + \frac{1}{r}$, and their joint resistance the reciprocal of this value, or $\frac{Rr}{R + r}$.

It is clear that the joint resistance of two or more conductors will be less than the resistance of either conductor singly, for the two conductors together present a greater area along which the current can flow than a single conductor, in the same way as there will be less resistance to the flow of water in a tin can with two holes in the bottom than in a can with only one hole whose area is less than the joint area of the two holes; and provided the height of the water or the pressure of the water in the two cans is the same, the can with two holes in the bottom will conduct more water in a given time than the can with only one hole.

If R represents a resistance of three ohms, and r a resistance of 2 ohms, their conductances will be $\frac{1}{3}$ and $\frac{1}{2}$ mho respectively; their joint conductance will be $\frac{1}{3} + \frac{1}{2} = \frac{5}{6}$ mho, and their joint resistance $\frac{6}{5} = 1\frac{1}{5}$ ohms.—Note: The term *conductance* is used as the inverse of resistance and *mho* as the inverse of ohm.

Let us now briefly examine the course of the current in the circuit represented in the diagram, Fig. 193, in order to arrive at some explanation of how one instrument measures the ampères of the current while the other measures the volts. At the commencement of this chapter we explained that the current flowing through a conductor measured in ampères is equal to the electromotive force of the current measured in volts divided by the resistance of the conductor measured in ohms; thus ampères $= \frac{\text{volts}}{\text{ohms}}$ or $C = \frac{E}{R}$.

Referring to our diagram, we will assume that the dynamo generates a current of 100 volts pressure, and that the voltmeter has a resistance of 5000 ohms. Assuming that all the lamps are switched off, the current which the dynamo will generate is dependent on the resistance of the voltmeter only; thus $C = \frac{100}{5000} = 0{\cdot}02$ ampères; but no current will flow through the ammeter in consequence of the circuit between that instrument and the generator being broken; for the connection between the positive and negative wires is made only when the lamps are turned on, excepting between those points where the voltmeter is connected.

Let us now turn on the first pair of lamps which have a joint resistance of 10 ohms. There are then two connections between the positive and negative wires, the voltmeter circuit having a conductance of $\frac{1}{5000}$ mho and the lamp circuit a conductance of $\frac{1}{10}$ mho. Their joint conductance will be $\frac{1}{5000} + \frac{1}{10} = \frac{501}{5000}$ mho, their joint resistance $\frac{5000}{501} = 9{\cdot}98$ ohms, and the current which will flow through it with the pressure of 100 volts, $C = \frac{100}{9{\cdot}98} = 10{\cdot}02$ ampères. Of this current the lamps will take $C = \frac{100}{10} = 10$

ampères, and the voltmeter the remainder, or $\frac{100}{5000} = 0{\cdot}02$ ampères, exactly the same as when the lamps were switched off.

In the same way, if the five pairs of lamps are turned on there will be six connections between the positive and the negative wire, with a total conductance of $\frac{1}{5000} + \left(\frac{1}{10} \cdot 5\right) = \frac{2501}{5000}$ mho, and a joint resistance of $\frac{5000}{2501} = 1{\cdot}9992$ ohms. The current which will flow through the resistance at the same pressure of 100 volts, $C = \frac{100}{1{\cdot}9992} = 50{\cdot}02$ ampères, of which the lamps will take $\frac{100}{2} = 50$ ampères and the voltmeter 0·02 ampères as before.

Supposing we increase the pressure of the current to 200 volts, then, when the lamps are all disconnected the whole current will pass through the voltmeter and its magnitude will be $C = \frac{200}{5000} = 0{\cdot}04$ ampère, that is exactly twice as great as when the pressure was only half as great, or 100 volts. Further investigation will show that the current which flows through the voltmeter varies exactly as the electromotive force or pressure of the current and is quite independent of the total current generated, or of any resistance which may be switched on outside the voltmeter circuit.

Three-wire System.—While examining the course of a current in a circuit it may be as well to describe the system of wiring for continuous currents known as the "*three-wire system*" which is being largely adopted at the present time, as it enables higher voltages to be used and twice the number of lamps to be lit with very little extra expenditure in the wiring.

As we have already mentioned, the voltage of the current used for lighting with incandescent lamps may not exceed about 220.

The voltage of alternating currents can be easily and economically raised or lowered, even on a small scale, by means of transformers; but this is not the case with continuous currents where a transformer can only be economically used in a large installation.

It is, of course, always possible to connect lamps in series and on the Central London Railway where the voltage of the current is about 500, five incandescent lamps are connected in series, so that the voltage between the positive and negative terminals of each lamp is only 100. This system, however, is only practicable in exceptional cases, as, besides other disadvantages which it possesses, the five lamps in series must necessarily be inseparable, so that if one is alight all must be alight and if one burns out or is otherwise extinguished all will be extinguished. For this reason lamps should always be connected in parallel if possible in order that any lamp may be switched off without disturbing the rest.

An installation on the three-wire system requires two generators connected in series; or the same effect may be produced with one generator having a double armature with two commutators and two sets of brushes, but the connections would be the same in either case. Fig. 194 shows the arrangement.

By adopting this system a voltage of say, 220 can be used for lighting and 440 for motive purposes, with the advantage that the wires need only be large enough to carry current at 440 volts pressure.

It will be seen that wire *a* leads from the positive terminal of dynamo I, and wire *c* leads to the negative terminal of dynamo I I, while wire *b* is neutral and may conduct current to dynamo I, or from dynamo I I, as shown by the dotted arrows on the diagram, according to which side of the circuit requires more current than the other. Examining the course of the current along the whole circuit

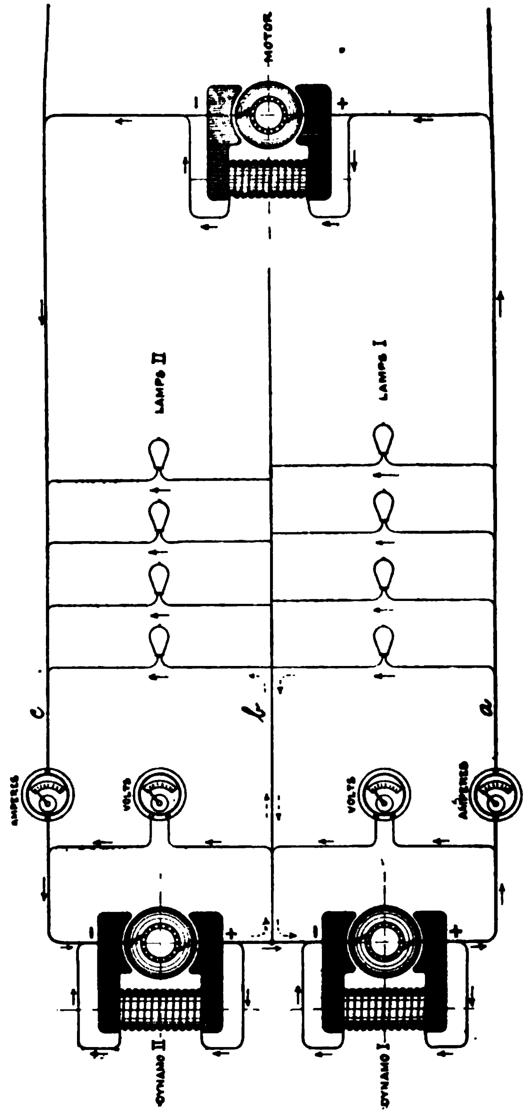
MOTOR
LAMPS II
LAMPS I
c
b
a
AMPERES
VOLTS
VOLTS
AMPERES
DYNAMO II
DYNAMO I

Fig. 194.

it may be assumed that dynamo II generates a current of, say, 220 volts, passing on to dynamo I, which, being wound the same as dynamo I I, also generates a current of 220 volts; but as the two dynamos are connected in series the current passing from one machine to the other is doubled in voltage without increasing in ampères.

An admirable representation of this may be seen in our air pump, Fig. 192, where the back of the piston represents the negative terminal of dynamo I I, and the front of the piston the positive terminal of dynamo I, while the wires *a*, *b*, and *c* are represented by the different portions of the pump *a*, *b*, and *c* respectively.

Just as the pressure of the air in the pump at *a* is + 1 lb., at *b* neutral, and at *c* – 1 lb., with 1 lb. difference of pressure between *a* and *b* and between *b* and *c*, and 2 lb. difference of pressure between *a* and *c*, so in the circuit, Fig. 194, we have a potential of + 220 volts at *a*, – 220 volts at *c*, and a neutral wire at *b*, with a difference of potential of 220 volts between *a* and *b* and between *b* and *c*, and a difference of potential of 440 volts between *a* and *c*.

The two sets of lamps I and I I are merely connected in series; and, if both sets require the same amount of current, no current at all passes along the wire *b* to or from the generators.

But if there were no connection between the wire *b* and the generators, supposing one of the lamps I burned out or otherwise became disconnected, it would at once affect all the lamps I I, which would burn very dimly, because the amount of current which the resistance of the three lamps allows to flow through when distributed over the four lamps would be insufficient, but having the wire *b* connected with the generators, the tendency would be for dynamo I I to at once yield a sufficient extra amount of current which, instead of flowing through dynamo I would flow along wire *b* and through the lamps I I to *c*.

In the same way, if one of the lamps I I were disconnected, dynamo I would yield an extra amount of current, which would flow from its positive terminal, through the lamps I and along wire *b* to its negative terminal. Thus it will be seen that wire *b* conducts either positive or negative current, and only as much as the difference between that required for lamps I and II so that very little current ever passes through it and only a comparatively thin wire is required.

The difference between the amount of current registered by the ammeters at *a* and at *c* is that which flows along wire *b*.

Motors may be connected from wires *a* to *b*, or from *b* to *c*, in which case a current of 220 volts is supplied to them; or they may be connected, as shown in the diagram, from wires *a* to *c*, thus supplying them with a current of 440 volts.

It is, of course, desirable to keep the resistances on each side of the circuit as nearly equal as possible, in order that both generators may have an equal amount of work to do, and that very much current may not pass along wire *b*, thus necessitating a large sectional area of metal.

CHAPTER XXV.

DISTRIBUTION OF LIGHT.

THE methods of distributing artificial light, whether for open spaces or for indoor illumination, must be very carefully considered. In too many instances a single powerful electric light or gas burner is placed in a position from whence its rays spread out in such a manner that the illumination obtained at the most distant point is considered sufficient for the purpose required. Such a system is, in principle, most wasteful, as in order to secure a sufficient degree of illumination of light at a few points, an enormous excess is wasted at the majority of the others, whilst the strain on the eyes of the individual whenever the direct rays from the powerful light source impinge upon them is most taxing.

The wonderful accommodating power of the diaphragm of the eye largely mitigates this evil, truly; but an evil it is, and one which is increasing. There can be no doubt whatever that the work of the professional oculist has been not a little enhanced by the ill-considered systems of artificial illumination so much in vogue during the past two or three generations. Now-a-days many people spend a considerable proportion of their lives, especially during the winter months, working by artificial light. Every time the direct rays from a light source impinge upon the retina, the iris, or "pupil," of the eye rapidly closes until the intensity of the rays passing through it is reduced to bearable limits. As soon as the direct rays cease to enter the eye the pupil expands in order that sufficient light from a less illuminated object in view can act upon the optic nerve, otherwise the object viewed would be invisible, or nearly so. This constant action of the pupil, or guardian angel of the eye, as it might be termed, combined with that on the optic nerve, and the crystalline lens, becomes most fatiguing, and in time unquestionably affects the power of vision.

The dazzling effect, as it is commonly called, of intense light, is perhaps most noticeable in a street or country road on a dark night, when the ordinary gas flame has been replaced by an incandescent burner. As the observer approaches the light the illumination is clearly perceptible up to the point at which the lamppost stands, but beyond that all is apparently darkness, by reason of the contrast. If the observer's eyes are shielded from the direct rays, the illumination of the immediate background will at once be seen to be fairly good. It was this effect, enormously intensified, which made it necessary to enclose electric arc lamps in opal or ground glass globes. It is not necessary to dwell on the point further at present, but it is eminently desirable that it should be clearly indicated, with a view to ensuring its avoidance to the utmost extent possible.

The first object to be kept in mind when designing an installation is that all parts of the place should be as far as possible equally illuminated, without undue shadows in any part. For this reason powerful arc lights should be reserved for large interiors and open spaces. For small interiors incandescent lights are at the present time most suitable. Many persons prefer the lights arranged round the room against the walls. It is, of course, largely a matter of taste; but, for the reasons above referred to, it is undoubtedly bad for the eyesight for the light source to be placed in a position from which the direct rays impinge upon the eyes. Apart from this by no means unimportant consideration, it is very much open to question whether wall-lights are always so effective as they are often claimed to be.

For instance, take the case of an ordinary sitting-room. In many instances pictures are hung upon the walls. What will be the effect on these when the light is held by a bracket on the wall about 12in. or 18in. in front or on one side of the picture? Again, if one wishes to read comfortably, the reader's back should be turned towards the light. If this is on a small bracket the reader would have to sit facing, or near to, the middle of the room, a position not always desirable. The older method of having the lights in a sitting-room as near the ceiling as possible, and fairly distributed is by far the best. If sufficient lighting power by this method cannot be obtained, then by all means use a small single light-source as close as possible to the object to be illuminated. But this is not the general illumination which is the object under consideration.

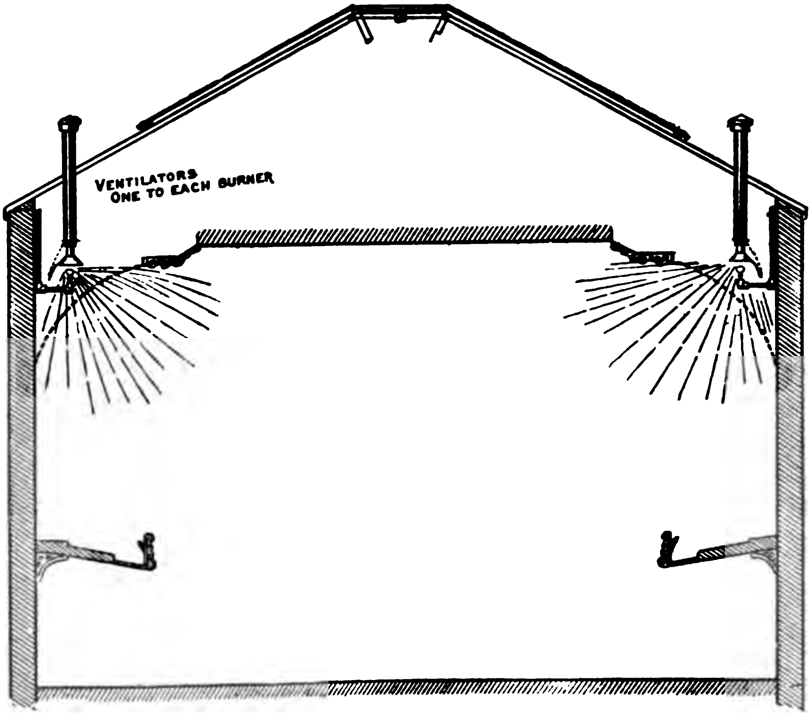

Fig. 195.

The method of diffused top-lighting is well exemplified in the case of many of our public rooms, in which incandescent lights are distributed over the ceiling, with the result that, whilst they do not distress the eyesight of the observer, a thoroughly uniform illumination is secured in all parts of the room.

The system adopted in certain halls, such as that arranged by Mr. Sugg at Reading, in which the lights are placed round the top of the walls behind glass screens (Fig. 195), so that the direct rays are invisible, is excellent. Another instance of the same kind is that at the Houses of Parliament, in which the gas lights are placed over glass screens in the ceiling, with the result that a perfectly even illumination is maintained.

One objection raised to these methods is that the expense is greater than would be the case if the lights were visible. This raises a point of economy which, although desirable and necessary in many instances, does not, and should not, carry all before it. Where the comfort and convenience of large numbers of people are concerned for many hours at a time, undue economy in regard to effective illumination will often entail eventually such serious results in respect to eyesight that it often really becomes the worst form of extravagance.

The first point, therefore, which must be considered is, that the lighting arrangements must be thoroughly equal to the requirements of the case. This brings us to the consideration of the most desirable working power of light at the immediate point of observation.

Many years ago Mr. Sugg suggested that the standard of artificial illumination should be the degree of illumination afforded by one standard candle placed at 1ft. distance from the surface to be illuminated. Sir William Preece subsequently proposed at the Paris Electrical Congress in 1889, the "lux," by which term he indicated the illumination afforded by a Carcel lamp acting at a distance of one metre. As the Carcel lamp is equal to 9·5 English standard candles, and the metre is equal to 3·2809ft., and the illumination is inverselyproportionate to the square of the distance,it follows that the quantity of light received upon a standard surface in the case of the lux would be practically the same as that proposed by Mr. Sugg. Strictly, a candle-foot is 0·882 of a lux or Carcel-metre, and a lux is 1·133 candle-foot. We may, therefore, adopt the "candle-foot" degree of intensity as a useful guide. For the purpose of working out the required intensity of a series of lights for illuminating a given area, Mr. Sugg has formulated the following definitions and the table given on the next page.*

"*Illuminating effect* is the *distance* from the surface to be illuminated, at which the standard candle must be placed to give the same amount of light as that supplied by a given light at a given distance. This may be found by dividing the distance of the light by the square root of its intensity (see Table LV.). Thus a 50-candle light at a distance of 15ft. would give an effect equal to that of one candle at a distance of 2·12ft., *i.e.*, $\frac{15}{7{\cdot}07} = 2{\cdot}12$.

"*Illuminating value* is the *intensity* expressed in candles of the light which would be required at a foot distance to produce the effect of the given light at its given distance. This is found by dividing the intensity by the square of the distance." Thus it may be desired to ascertain the strength of the light which would be required at a foot distance from a given object to produce the effect of a sixteen candle lamp placed 6ft. from that object. The answer is $\frac{16}{6^2} = 0{\cdot}44$, which is the "candle-foot," or "illuminating" value of the light obtained under the conditions given.

If it is required to ascertain the candle-power of a lamp which should be placed at a given distance from the object to be illuminated, in order that the degree of illumination shall be equal to that which would be afforded by one candle at a foot distance, any number in the Table LV. may be read as *candle-power of the lamp required,* and its square root as the *distance in feet at which the lamp is to be placed.* Thus, let it be required to illuminate an object to the extent of a "candle-foot" by means of a lamp which must be placed 9ft. distance: Then $9^2 = 81$ = the illuminating power of the lamp required.

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* Abstracted by permission from the "Gas Engineers' Pocket Almanac," W. Sugg and Co.

The origin of the expression "candle-foot" is related by Mr. Sugg to be as follows* :—"The only case in which he (Mr. Sugg) had been able to feel satisfied with the lighting requirements was that of the Grand Committee-room of the House of Commons. A piece of paper was given to him with some pencil marks upon it, and his instructions were that a sufficient amount of light should be given to enable a man with ordinary eyes to read what was on the paper. He had only to get half a dozen men to read the paper, and see at what distance he held it from a standard

TABLE LV.

Table of Square Roots for the Calculation of Illuminating Effect.

No.	Square root.	No.	Square root.
1	1·0000	17	4·1231
2	1·1442	18	4·2426
3	1·7320	19	4·3589
4	2·0000	20	4·4721
5	2·2360	25	5·0000
6	2·4492	30	5·4772
7	2·6457	35	5·9161
8	2·8284	40	6·3245
9	3·0000	45	6·7082
10	3·1623	50	7·0711
11	3·3166	100	10·0000
12	3·4641	200	14·1421
13	3·6055	300	17·3205
14	3·7416	400	20·0000
15	3·8730	500	22·3607
16	4·0000		

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* Institution of Civil Engineers. Discussion on Mr. Trotter's paper, vol cx., part iv.

candle. Then the problem was solved, the light required being one candle-foot."

In the opinion of Mr. Trotter the candle-foot is a very convenient and "comfortable" illumination. It is for most people the best illumination for reading, and is to be found on most well-lighted dining tables and billiard tables. More than 2 candle-feet is seldom attained in artificial illumination.

The degree of illumination of certain public places may be gathered from the following tabulated results of observations by General Festing, Mr. A. P. Trotter, and others:—

TABLE LVI.

Date.		Candle-foot.
1892	President's desk, Inst. C.E.	0·8*
	South Kensington Museum:—	
1888	North-east Water Colour Gallery (gas)	1·81†
,,	South-east ,, ,, ,, ,,	2·32†
,,	Jones' Bequest Gallery (6 glow lamps)	1.72†
,,	Raphael Gallery (arc)	2·26†
,,	Sheepshanks Gallery (arc)	3·12†
1892	Sculpture Court (6 arcs in sight)	0·55*
,,	,, ,, (8 ,, ,,)	0·8*
,,	Silversmiths' Court (10 arcs in sight)	2·6*
,,	Japanese Court (8 arcs in sight)	1·6*
,,	Great Hall (9 arcs in sight)	2·4*
,,	Gallery over Silversmiths' Court	3·5*
,,	Corridor (glow lamps)	0·65*
,,	Charing Cross Railway Station, max. (arc)	0·4 to 0·5*
,,	,, ,, ,, ,, min. (arc)	0.05*
,,	Cannon-street Station, max. (arc)	0.4*
,,	,, ,, ,, min. (arc)	0·025*
,,	City of London, Cornhill	0·25*
,,	,, ,, ,,	0·1 to 0·5‡
,,	Whitehall	0·1 to 0·5*
—	Great George-street, Westminster (5ft. gas lamps)	0·9 to 0·005*
—	Lyric Theatre (without arc or limelights)	3·8*
—	Prince of Wales' Theatre	2·9*
—	Trains on Metropolitan and District Railways (breast high)	0·3 to 0·9*
—	Lime-street, Liverpool (gas, flat flame)	0·25 to 0·58§

* Trotter. † General Festing. ‡ Preece. § Boulnois.

It has been held that outdoor illumination commences to be useful only when it is comparable to moonlight.

The following determinations of the intensity of full-moonlight are on record, viz.:—

TABLE LVII.

Authority.	Moonlight = 1 candle at feet distance	
Plummer*	8·72	Average = 7.77
Dibdin†	7·20	
Dibdin†	6·83	
Dibdin†	8·60	
Trotter,‡ average	8·00	

* "Monthly Notices," Roy. Ast. Soc., vol. xxxvi.
† "Proceedings," Roy. Soc., vol. li.
‡ Inst. C.E., see *ante.*

Taking this average of one candle at 7·77ft. distance, moonlight is therefore equal to 0·017, or, say, one-sixtieth of a foot-candle.

It will be understood that these determinations apply to full moon, but at different zenithal distances. The point in all its phases is a complex one, but the above general results will be sufficient for our present purposes.

Reflectors and Globes.—The importance of reflection in the distribution of light must not be overlooked, as by its judicious utilisation greatly enhanced results may be obtained, whilst in some cases the use of reflected light only has been found to give the most satisfactory results, where, for instance, operations of a delicate nature, such as fine wheelwork and other mechanician's work, have to be performed. Mr. G. Kapp has described* the following method of utilising only reflected rays in the case of a factory in Berlin, where great difficulty had been experienced in finding a suitable light. The ordinary arc lamp would not do because it cast too strong a shadow, and, in turning arbors and axles, and milling toothed wheels, a uniformly diffused light was required. Glow lamps, which might have fulfilled this condition, were too much exposed to breakages from chips flying about and the carelessness of workmen. The solution which the manager of the shop found was to put arc lights into big funnel-shaped covers, white-washed inside, and to hang them up 8ft. from the floor. The ceilings were kept white-washed, and the effect of the lighting was excellent. The arc could not be seen, being entirely hidden by the funnels, but the room was filled with a very soft diffused light. Another similar instance is that quoted by Mr. G. F. Deacon, who referred to the public library in Liverpool, the Picton Reading-room, as one of the best illuminated rooms in the kingdom.

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* Institution of Civil Engineers, vol. cx., part iv., p. 72.

It is a circular room, 100ft. in diameter, with a dome ceiling. For the purpose of illuminating the tables and floors he put in the centre of the room three arc lights. Under them he put an opal chalice 12ft. in diameter, resting on an ornamental vase. He then white-washed the dome, and the effect was excellent. The absolute amount of light was nearly uniform over the whole surface of the tables.

The degree to which white surfaces reflect light is not generally so well understood as it should be. According to Mr. Trotter, good paper, plaster of Paris, and even white-wash, have a reflecting power equal to that of ordinary looking glass, viz., about 85 per cent.

The following interesting account of the holophane globes was given in the *Progressive Age*, December 1st, 1899 :—

"The inner and outer surfaces of holophane globes are covered with very fine corrugations or prisms. The corrugations on the inner surface run vertically, and the prisms on the exterior surface run horizontally. When the globe is placed over any form of light, such as the arc lamp, the incandescent electric lamp, the Welsbach incandescent gas burners, an oil lamp or an acetylene flame, the combined effect of these two sets of prisms is to spread or diffuse the light over the entire surface of the glass, the objectionable and injurious glare of the intense light-source disappears, and in its place the globe seems filled with bright but mellow rays of light. But, while the glare of the central light is thus broken up, there is no loss comparatively in the illuminating power of the burner, and the light is directed, in addition, to where it is most needed.

"Upon lighting an uncovered Welsbach burner and placing a sheet of white paper on the table beneath it, it will be seen that while the burner has the appearance of giving an immense amount of light, yet the illumination is not well distributed. If we look about the room, the walls and ceiling seem well lighted; but on resting the eye upon the sheet of paper below the burner, one is sensible of a defect. The reason is that the incandescent burner directs most of its diverging luminous rays out horizontally, very little light being thrown downward where it may be really required. The intense glare of the flame also tends to contract the pupil of the eye, and prevents it from taking in all the rays thrown upon any object. The clearness with which the eye sees any object depends upon the number of rays from that object which fall upon the optic nerve. When the light is too strong the pupil contracts, the number of rays is diminished, and the object is seen less distinctly. If, now, the eye is fixed upon the paper while the burner is covered with a holophane globe the paper at once becomes well illuminated, and the candle-power of the rays thrown downward is evidently greatly increased. The walls of the room seem as well lighted as before, but the light on the floors and tables has been greatly improved. The reason is that the rays of light that formerly escaped upward and merely illuminated the ceiling, have been reflected and refracted downward where they are needed. The *amount* of light emitted by the burner is not increased, of course, but merely directed where required. It will also be observed that through thus increasing the surface of the light-giving body, the strain upon the eye is relieved and the light in the room is agreeably diffused.

"*Principle of Construction.*—If we take a globe from which the outer prisms have been removed, leaving only the interior vertical corrugations, which are all alike in section, and place it upon the burner, it will be seen that the effect of the vertical interior corrugations is to spread the light out laterally across the globe, illuminating it from edge to edge, and the flame, instead of being concentrated, becomes practically the size of the globe; but one will also notice that the rays are not otherwise affected by these inner ribbings, the principal portion of the light is still thrown outward. These corrugations only serve to destroy the glare; they diffuse the light, but do not distribute it in any way.

"If we now take a globe from which the interior corrugations have been removed, leaving only the exterior horizontal prisms, it will be seen that the profiles of these prisms vary; as a matter of fact, no two are alike, and each one is specially calculated with reference to the position it occupies on the surface. It is by means of these exterior prisms that the light is controlled and directed. If we observe the effect they have upon the lighted burner, we see that the flame appears to be elongated into a narrow strip extending from the bottom to the top of the globe; the effect of the interior ribbings alone was to spread the light across the globe so that two sets of prisms acting together cause the light to be spread evenly over the entire surface, and it is from this feature that the system derives its name, as the word "holophane" (taken from the Greek) means wholly luminous.

"Since the introduction of high candle-powers, lighting experts have been studying to find the best means of overcoming objectionable and injurious glare. Globes of opal glass, ground, frosted and figured glass have been devised. Some of these, such as the opal, do overcome the glare, others reduce it partially; but all of them do so only by absorbing a large percentage of the original light. In case of opal glass this absorption or loss amounts to as much as 50 per cent. All such globes diffuse the light, but none of them make any attempt to direct the rays.

"Perfect diffusion not only does away with all sharp shadows, but produces a softened and evenly distributed light which has marked hygienic advantages, preventing irritation of the eyes, and to a large extent the particular diseases of the optic nerves that result from it.

"The prisms, it is claimed, also whiten the light by resolving many of the colour rays. This is a distinct advantage, as the decorations of rooms and the tints of pictures and fabrics are not appreciably changed.

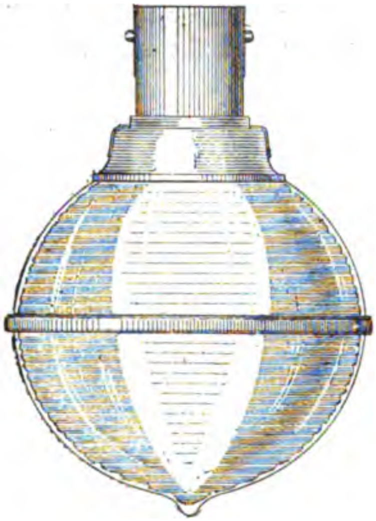

Fig. 196.

"Globes of this character serve to hide the mechanism of the burner, tending to produce an ornamental effect; and although they are made of pressed glass, they somewhat resemble cut glass effects."

Fig. 196, the spiral globe introduced by the Spiral Globe Company, consists of a light-refracting and diffusing envelope for an electric incandescent or glow lamp, composed of a closely wound spiral of glass rod or circular section (which serves both to screen the dazzling filament and increase the effective illuminating power of the lamp) contained within an outer protective crystal cover.

It has been demonstrated that this effective increase of illumination is very large, for whereas an ordinary 16 candle-power electric incandescent lamp (when hung vertically as is usually the case) will illuminate the surface towards which it is directed with an effective light of 10 candle-power only, this self-same lamp, when enclosed in the spiral globe will produce an effective light equal to about 23 candle-power with the same consumption of current

CHAPTER XXVI.

EFFICIENCY OF ARC AND ELECTRIC INCANDESCENT LAMPS.

THE intensity of various arc and incandescent lamps was formerly greatly exaggerated. For instance, in many cases three or four hundred candle-power lamps were calculated as being equal to a thousand candles. This error was soon corrected by the results of the photometrical experiments made by the writer under the direction of the Metropolitan Board of Works in connection with the Thames Embankment experiments with the Jablochkoff arc lights.

The following extracts from the report of Sir Joseph Bazalgette, the engineer, and Mr. T. W. Keates, the chemist to the Board, form an interesting and valuable contribution to the photometry of the arc lamp, as the principles there involved are still those concerned in all similar installations.

*In consequence of the dazzling nature of the electric light, and its tendency to injure the sight of persons exposed to its influence, it is necessary that the naked light, should be screened. Opalescent glass globes have been used by the French society both in Paris and in London, and these have been in use on the Embankment, with the exception of one lamp, from first to last. The effect of this opalescent glass is to soften and diminish the light, so that it is possible to look fixedly at the globe without any distress, but at the same time the available light is lowered to a very great extent. A different kind of globe, having a

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* "Report on Experiment with the Electric Light on the Victoria Embankment." By Sir J. W. Bazalgette, C.B., Engineer, and T. W. Keates, Consulting Chemist, Metropolitan Board of Works, May, 1879.

frosted surface, has been used for some time under the Hungerford Railway Bridge; this globe stops much less of the light than the opalescent glass.

A number of experiments was made at the machine house on the Embankment, where a complete photometer was fitted up. These experiments were (1) upon the naked light, (2) upon a light with opalescent globe, (3) upon a light with a frosted globe. The measurements were made horizontally in each case.

In every experiment the electric light was placed 240in. from the measuring light, and the photometer screen moved between them, a star disc being employed in consequence of the difference in the colour of the lights, precluding the the use of the ordinary greased Bunsen disc.

Twenty readings or observations were made in each experiment, both with the open and shaded lights. Eight experiments were made on as many different nights. The following are the results obtained:—

TABLE LVIII.

Naked light	378·1 sperm candles
Opal globe	154·9 sperm candles
Frosted globe...	265·0 sperm candles

The light obstructed by the opal globe was, therefore equal to 59 per cent.; by the frosted globe only 29·9 cent' These results shew the effect of enclosing the electric arc by globes, and serve as useful guides to indicate the loss of light resulting in all similar cases.

When the arc lamp was introduced on the Thames Embankment in 1879, some experiments were made at the suggestion of the writer to ascertain the effect of enclosing the carbons in closed glass vessels, with a view to reducing the rate of their oxidation. The peculiar action of the Jablochkoff "candle," however, was not favourable to the method, an undue amount of deposit appearing on the surface of the glass, largely reducing the effective power of the light. Later on, when the improved forms of the Brush and similar lamps were introduced, further trials were made by the writer in conjunction with Mr. de Segundo, with most satisfactory results, it being found that the life of the carbons could be prolonged up to as much as ten times, but at this rate the character of the arc was not so satisfactory, as a carbon button formed on the negative carbon, with a consequent dimming of the light. When a slow stream of air was allowed to enter the small encircling glass pear-shaped vessel surrounding the arc, just sufficient in quantity to oxidise the particles of finely divided carbon as they were carried from the positive to the negative poles, the light remained perfectly steady and of the original intensity. The following are some typical results of the experiments thus made:—

TABLE LIX.

Time.	Length of carbon in arc lamp No. 1 without economising globe. Inches.	Length of carbon in arc lamp No. 2 with economising globe. Inches.
12·00	2·21	1·18
12·10	2·43	1·23
12·20	2·61	1·32
12·25	2·75	1·40
12·35	2·81	1·42
12·40	3·00	1·50
12·50	3·19	1·54
1·00	3·40	1·62
1·45	4·21	1·98
2·15	4·71	2·25
2·25	4·88	2·26
2·53	5·31	2·42
3·28	5·81	2·60

Relative Consumption.

Without apparatus, 12·00 o'clock to 3·28 ... 3·6in.
With apparatus, „ ... 1·42in.

$$\text{Saving } \frac{(3{\cdot}6 - 1{\cdot}42)\ 100}{3{\cdot}6} = 60 \text{ per cent.}$$

Table LX.

Time.	Length of carbon in arc lamp No. 1 without economising globe. Inches.	Length of carbon in arc lamp No. 2 with economising globe. Inches.
12·40	1·50	·97
12·50	1·97	1·08
1·40	2·61	1·30
1·50	2·80	1·35
2·10	3·14	1·47
2·35	3·50	1·60
2·40	3·60	1·62
2·50	3·76	1·63
3·00	3·91	1·75
3·15	4·18	1·82
3·25	4·30	1·90
3·35	4·43	1·93

Relative Consumption.

Without apparatus	2·93in.
With apparatus	0·96in.

$$\text{Saving } \frac{(2{\cdot}93 - {\cdot}96)\ 100}{2{\cdot}93} = 67{\cdot}2 \text{ per cent.}$$

Table LXI.

Time.	Length of carbon in arc lamp No. 1 without economising globe.	Length of carbon in arc lamp No. 2 with economising globe. Inches.
3·40	2·1	·85
3·50	2·2	·90
4·00	2·4	·99
4·10	2·53	1·04
4·20	2·60	1·13
4·30	2·85	1·21
4·40	3·00	1·30
4·50	3·13	1·40
5·00	3·29	1·50
5·10	3·40	1·60
5·20	3·59	1·70
5·30	3·75	1·78
5·40	3·90	1·85

Relative Consumption.

Without apparatus	**1·8in.**
With apparatus	**1·0in.**

$$\text{Saving } \frac{(1\cdot8 - 1\cdot0)\ 100}{1\cdot8} = 44\cdot45 \text{ per cent.}$$

TABLE LXII.

Time.	Length of carbon in arc lamp No. 1 without economising globe. Inches.	Length of carbon in arc lamp No. 2 with economising globe. Inches.
11·50	4.32	2·00
12·00	4·50	2·05
12·10	4·69	2·12
12·20	4·85	2·13
12·30	5·00	2·19
12·40	5·15	2·20
12·50	5·30	2·25
1·00	5·49	2·29
1·10	5·54	2·31

Relative Consumption.

Without apparatus	**1·22in.**
With apparatus	**0·31in.**

$$\text{Saving } \frac{(1\cdot22 - 0\cdot31)\ 100}{1\cdot22} = 74\cdot6 \text{ per cent.}$$

Just as these results had been arrived at by a course of laborious photometrical and electrical testings, it was ascertained that patents had been secured in England and America for precisely the same method. The system is now in use in the form of the Jandus lamp, the special features claimed for it being that one pair of carbons consuming 4 ampères will last for about 200 hours without any attention whatever; with 5 ampères for 130 to 150 hours, and with 6 ampères from 100 to 120.

From tests made by Mr. Thomas Hesketh, and published in the *Electrician* on April 9th, 1897, the following results were obtained :—

"From comparative photometric tests recently taken by the writer, the distribution of light from a 10-ampère direct-current lamp, burning 18 mm. and 12 mm. carbons, with 46 volts across the arc, and fitted with an opaline globe, is plotted out in Fig. 197.

"Similar tests were taken of the emission of light from a 'Jandus' enclosed arc lamp, burning 5·5 ampères with 78 volts at the carbons; the results are shown in Fig. 198.

"Fitted as this was with the inner and outer globe of opalescent glass, the spreading of the rays was less than might have been expected. The intensity of the horizontal flux is partly to be accounted for by the egg-shaped curve of the inner globe, acting as a reflector, and throwing up some of the lower hemispherical beams. Principally, the great advantage is derived from the extreme length of arc, the flatness of the carbon points, and the almost entire absence of hollow crater in the positive carbon.

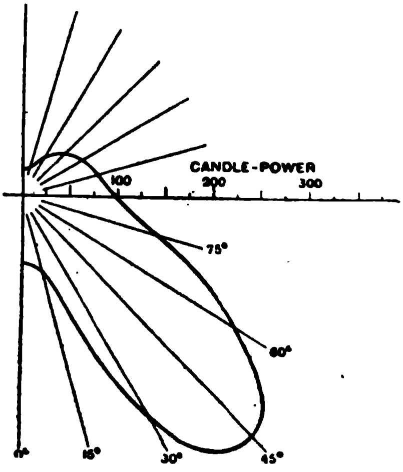


Fig. 197.—Curve of Light from Ordinary Open-air Arc fitted with Opaline Globe.

"The effect the improved distribution of light from these lamps will have upon public street lighting will be more readily appreciated from a glance at Fig. 199, where the relative illuminating powers of the two lamps are shown side by side.

"It will be seen from these that, although at close ranges, the light from the open arc is some four times as great as that from the enclosed, at distances beyond two and a-half times the height of the arc lamp-post, the 'Jandus' gives more than twice the light of the older form of lamp, and regularly maintains the advantage.

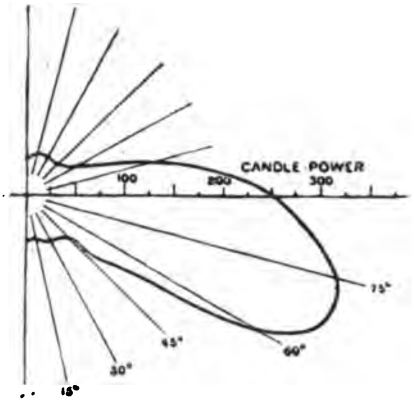
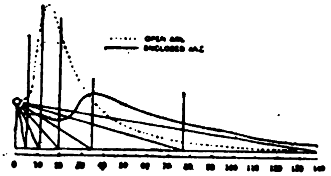


Fig 198.—Curve of Light from "Jandus" Lamp fitted with Inner and Outer Globes of Thin Opaline Glass.



Scale of feet. (Height of post = 20ft.)

Fig. 199.—Curves showing the Relative Illuminating Powers of "Jandus" and Ordinary Open-air Arc Lamps taking equal Electrical Energy.

"This natural effect cannot be too highly appreciated. Engineers having control of the public lamps should carefully guard against a false impression being created by the light intensities immediately about the base of the lamp-post. Excessive light here is not required; but at places 25ft. and 30ft. away, double the illumination of that which was previously to be obtained is of the greatest importance.

"From the foregoing considerations it is reasonable to expect the arc lamp of the future will be of air-tight pattern, and will have sacrificed a portion of its carbon diameters—and consequently its hours of burning—for the increased light resulting."

The necessity for carefully testing the illumination afforded by any proposed light is well shown in the Thames Embankment experiments above referred to, and estimates for installations should not be prepared before the actual illuminating value of the proposed lights is fully ascertained.

With regard to the quantity of light afforded by the incandescent electric lamps, and the effect of use upon them, the following series of tests by the writer in November, 1892, will be of interest:—

Each lamp was tested in three directions, viz.:—horizontally in two directions, *i.e.*, one with the plane of the curvature of the filaments placed at right angles to the photometer bar, and the other with the plane of curvature in a line with the photometer bar, or, shortly, with the incandescent filaments "flat" and "edge" to photometer; also perpendicularly in one direction, *i.e.*, measuring those rays thrown down when the lamp is inverted, and in the direction of the apex of the lamp.

In estimating the actual intensity of the lamps, the mean of the two horizontal measurements has been adopted.

The average luminous energy per reputed 16 candle-power lamp was thus found to be 13·01 candles, while that of the reputed 8 candle-power lamp was 7·30 candles. The average voltage for 16-candle lamps was 98·02, and ampères ·599, the watts per 16-candle lamp being 58·8; while the current required for 8-candle lamps was volts, 99·58;

ampères, 0·424; equal to 42·3 watts. The number of watts per actual candle respectively was 4·52 and 5·79. The average percentage deficiency per 16 candle-power lamp was 25·86, and that of the 8 candle-power lamp 8·4.

A large number of measurements at various intermediate angles would have doubtless ensured greater accuracy, but for practical purposes those now submitted may be taken as sufficiently approximate. In order that the extent of error thus introduced might be ascertained, a special set of tests with one lamp was made in which the lamp was tested at every 10°.

The effect of a decrease in the intensity of the current was also carefully examined, and the results were tabulated.

From these it appears that when the voltage of the current falls from 99 to 96, the loss in candle-power is from 15·0 to 10·9, or 27·3 per cent.; whilst when it falls from 96 to 90, the loss of candle-power is from 10·9 to 7·5, or exactly 50 per cent. from its initial value.

The extent to which the light of the incandescent lamps is diminished by continued use is of importance. A series of experiments carried out to ascertain this loss showed that a lamp having an initial intensity of 14·8 candles, and maintained at a practically constant current of 100 volts and 0·5 ampère, fell in 100 hours to 14·0 candles, in 250 hours to 11·5 candles, and in 500 hours to 10·5 candles, remaining fairly constant at that intensity for another 250 hours. From these results it is evidently desirable to cause a lamp to be subjected to the electric current at which it is intended to be worked for some little time before it is measured, as if the initial intensity is accepted as the average intensity, the lamp will be credited with too high a value.

The practical outcome of these testings is :—(1) That the public should be protected against any diminution of the strength of the current by systematic testings, and the companies subjected to penalties in the event of default. (2) That all lamps should be tested for their illuminating power when submitted to their prescribed current. (3) That 16 candle-power lamps are more economical in relation to light and current than 8 candle-power lamps.

The efficiency of the incandescent and arc lamps has also been carefully studied by Professor L. Nichols, of the Cornell University, under whose directions Mr. Merritt and Mr. Hatsuné Nakano carried out a series of most interesting and valuable experiments.*

After a preliminary series of tests of incandescent lamps by means of a calorimeter, Mr. Merritt carried out a series of determinations with the thermopile. The results for the four lamps are as follows:—W is the total energy expended, measured in watts; L is the energy of the light, also measured in watts; and C.P. is the candle-power.

TABLE LXIII.

Lamp B.—An Edison 16 *Candle-power Lamp. Resistance =* 249 *Ohms.*

E.M.F.	W.	C.P.	L.	$\frac{\text{L.}}{\text{W.}}$	$\frac{\text{L.}}{\text{C.P.}}$
63·0	25·4	0·3	0·42	·016	1·61
74·6	37·8	1·0	0·77	·021	0·79
85·4	52·5	2·5	1·96	·037	0·78
99·0	72·2	6·3	4·30	·059	0·68
116·0	102·0	15·2	7·38	·072	0·49

Lamp C.—Weston 16 *Candle-power. Cold Resistance =* 402 *Ohms.*

E.M.F.	W.	C.P.	L.	$\frac{\text{L.}}{\text{W.}}$	$\frac{\text{L.}}{\text{C.P.}}$
72·0	21·6	0·4	0·46	·021	1·27
87·4	33·5	1·5	1·10	·033	0·76
102·0	47·8	4·4	2·09	·044	0·48
117·0	66·1	10·7	3·19	·048	0·30

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* These researches were published in America, those by Mr. Merritt in a contribution to the American Association for the Advancement of Science, Cleveland, August, 1888, and those by Mr. Hatsuné Nakano in a paper published in the "Transactions" of the American Institute of Electrical Engineers, Vol. vi., 1889.

TABLE LXIII. (*continued*).

Lamp D.—Weston 16 *Candle-power,* 70 *Volt. Resistance* = 152 *Ohms.*

E.M.F.	W.	C.P.	L.	$\frac{L.}{W.}$	$\frac{L.}{C.P.}$
43·0	25·8	0·5	0·53	·021	1·06
50·7	36·0	1·6	0·97	·027	0·62
60·5	52·0	5·2	2·03	·039	0·39
67·5	65·5	11·0	3·95	·060	0·36

Lamp E.—Bernstein 8 *Candle-power. Resistance* = 11·3 *Ohms.*

E.M.F.	W.	C.P.	L.	$\frac{L.}{W.}$	$\frac{L.}{C.P.}$
12·2	25·2	0·2	0·20	0·008	1·00
13·4	30·8	0·5	0·41	·013	0·84
15·0	40·4	1·3	0·75	·018	0·57
16·4	53·2	4·1	2·03	·038	0·50

None of the lamps tested were of the most recent styles, all being made previous to 1886. All the lamps also had been used a greater or less time before the tests were made. Lamps B and E especially had seen a great deal of use, and had their glass globes slightly blackened.

From these results it will be seen that the energy per candle-power varies from 1·5 watts at 0·5 candle-power to about 0·3 watts at 16 candle-power. In every case the intensity of the light, as measured by its candle-power, increases more rapidly than the energy of the light. In this connection it is interesting to compare the value of the mechanical equivalent of a candle-power of lamplight, found by Dr. J. Thomson some twenty years ago.* His method was similar to that used in these experiments. A cell of distilled water was used instead of an alum solution, and no correction was made for the dark heat passing through. To get absolute measurements of energy he standardised his thermopile by means of Leslie tubes. He found the energy of one candle-power of light from an oil lamp to be 2·5 watts, and for a gas flame and a standard candle the value was very nearly the same. This is considerably larger than the greatest value now found. A part of the difference might be accounted for by the correction for dark heat passing through the water, which Dr. Thomson neglected, and the standards of light used in the two cases may have been different. It is hard to believe that the temperature of the incandescent matter in an oil flame is less than that of a lamp filament at 0·5 candle-power. Recent spectro-photometric determinations by Dr. E. L. Nichols and Mr. W. S. Franklin[*] show that the light from a gas flame is of almost exactly the same quality as that from an incandescent lamp at 16 candle-power. This would seem to indicate that the incandescent matter in a gas flame is at about the same temperature as the lamp filament.

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* Julius Thomson. "Das Mechanische Aequivalent des Lichtes." Pogg. Ann. cxxv., p. 348.

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[*] Pro. A.A.A.S. Cleveland meet 1888.

CHAPTER XXVII.

COMPARISON OF COST AND HEATING EFFECT OF LIGHTING BY GAS AND ELECTRICITY.

THE cost of light obtained by the consumption of gas in suitable burners is ascertained by the consideration of the following three principal factors:—First, the quantity of gas consumed in terms of cubic feet per hour; second, the illuminative value thereby produced, commonly spoken of as the "illuminating power;" and third, the cost of the gas per 1000 cubic feet.

There are various other considerations to be taken into account, such as cost of fittings, globes, mantles (when used), &c., which must not be overlooked when making exact comparisons.

In the case of light produced by the agency of the electric current, the equivalent factors are:—First, current stated in terms of watts; second, illuminating power; and third, the cost of current.

For the purpose of fixing the commercial value of the current, the "Board of Trade unit" is adopted. This unit is the equivalent of 1 kilowatt = 1000 watts, acting during one hour.

The watt is the product of the *quantity* of the current, expressed in "ampères," and its *intensity* expressed in "volts." Thus 100 volts × 10 ampères equal 1 kilowatt, which, acting during one hour, equals one Board of Trade unit.

In the words of the Fourth Schedule of the Board's form of Provisional Order under the Electric Lighting Acts, 1882 and 1888, it is stated in regard to maximum prices, that "in this schedule the expression unit shall mean the energy contained in a current of 1000 ampères flowing under an electromotive force of one volt during one hour."

If a light having an intensity equal to that of sixteen standard candles is obtained by means of coal gas, burning in an Argand burner at the rate of 5 cubic feet of gas per hour, it is evident that in order to obtain 1000 candles of light by such means we must consume 5 × 1000 ÷ 16 = 312 cubic feet of gas. If the gas costs 3s per 1000 cubic feet, then the cost of the gas actually consumed = 36d. × 312 ÷ 1000 = 11·232d.

To obtain the same degree of illumination, viz., sixteen candles, by means of an electric current acting in an incandescent lamp, we shall probably use up current at the rate of, say, 60 watts per hour, which, on the basis of 6d. per Board of Trade unit, will be 60 × 1000 ÷ 16 = 3750 watts = 3·75 Board of Trade units = 1s. 10½d., *i.e.*, sixteen candles by the electric current costs 1s. 10½d. against 0s. 11⅕d. by gas.

From this it will at once be seen how important it is that before a definite comparison can be worked out, all the data must be clearly ascertained.

It is useless to assume the actual intensity of one light or the other. They must be accurately measured, otherwise the comparison will be as valueless as it would be if the price of the gas or that of the electric current were guessed at.

When a comparison is made with the Welsbach incandescent gas lights the results are very different. For instance, if a new Welsbach mantle affords light equal to sixty candles when consuming gas at the rate of 3·5 cubic feet per hour, the cost of the gas being, as before, 3s. per 1000 cubic feet, then for 1000 candles of light during one hour the cost will be 3·5 × 1000 ÷ 60, = 58 cubic feet, and 36d. × 58 ÷ 1000, = 2·088d. instead of 11·232d. for gas consumed in an Argand burner, as shown above.

In like manner, the cost of light obtained from any form of gas burner can be compared with that from any electrical system. But it must be remembered that in such calculations the quality of the gas used, stated in "candle-power," should be given as well as its price, for quality varies greatly, as already stated.

It is obvious that a high quality of gas at a low price will show a more favourable result to gaseous lighting than would a low quality of gas at a high, or comparatively high, price per 1000 cubic feet.

Without this qualification comparisons of relative cost at different localities would be misleading. To take extremes, 1s. 9d. per 1000 cubic feet for 15·5 candle gas in a coal-producing district would show a very different ratio to electric lighting than would gas of 14·0 candle-power in an agricultural district, at 4s. 6d. per 1000 cubic feet; to say nothing of such prices as those which commonly prevail on the Continent and in America.

Table LXIV. will probably be of assistance in making comparisons of the cost of *equal quantities of light* by different methods, apart from questions of maintenance, repairs, &c.:—

TABLE LXIV.

Cost of producing 1000 *CANDLES of Light during One Hour.*

	Pence.
BY ELECTRICITY, at 4d. per Board of Trade unit:—	
Arc lamp, 450 candle-power, 250 watts	2·2
Arc lamp, with frosted globe, 250 candle-power, 250 watts	4·0
Arc lamp, with opal globe, 150 candle-power, 250 watts ...	6·7
Incandescent lamp, 16·0 candle-power, 50 watts	12·5
Nernst lamp, 65·0 candle-power, 100 watts	6·2
COAL GAS, 16·0 candle-power, at 3s. per 1000 cubic feet:—	
Flat-flame burners, 13 candle-power, 5ft. per hour	13·8
Argand burners, 16 candle-power, 5ft. per hour	11·2
Welsbach mantle (say) 60 candle-power, 3·5ft. per hour ...	2·1
"Intensified" mantle, 300 candle-power, 10·0ft. per hour	1·2
PETROLEUM:—	
Kitson's incandescent oil lamp, 1000 candle-power	0·8
Flat-flame lamp, 9·5 candle-power at 617 gs. per hour, 9·5 lb., at 1d.	9·5

Sperm :—	Pence.
Candles, 17 lb., at 1s. 6d. per lb.	25s. 6d.
Oil, Keates' lamp (16 candles), 8·2 lb. at 4½d. per lb.	37·0
Colza :—	
Oil, carcel lamp (9·5 candles), 9·7 lb., at 3½d. per lb.	34·0
Oil, in hand-lamp = 1·6 candles, 192 grns. per hour	59·5

On the other hand, if the comparison is to be made on the basis of any one light source with another, apart from the question of *relative intensity,* then Table LXV. may be referred to:—

Table LXV.

Cost of EACH LIGHT, per Hour.

Electricity, at 4d. per B.T. unit :—	Pence.
Arc lamp, 450 candle-power	1·00
Arc lamp, frosted globe, 250 candle-power	1·00
Arc lamp, opal, 150 candle-power	1·00
Incandescent lamp, 16 candle-power	0·20
Nernst lamp, 65 candle-power	0·40
Coal Gas, 16·0 candle-power, at 3s. per 1000 cubic feet :—	
Flat-flame burners, 13 candle-power, 5ft. per hour	0·18
Argand burners, 16 candle-power, 5ft. per hour	0·18
Welsbach incandescent, 60 candle-power, 3·5ft. per hour	0·13
"Intensified" incandescent, 300 candle-power, 10·0ft. per hour	0·36
Petroleum :—	
Kitson's incandescent oil lamp, 1000 candle-power	0·80
Flat-flame lamp, 9·5 candle-power	0·09
Sperm Candles, 1·0 candle-power	0·31
Sperm Oil :—	
Moderator lamp, 16·0 candle-power	0·60
Colza Oil :—	
Carcel lamp, 9·5 candle-power	0·32
Hand lamp, 1·6 candle-power	0·10

The Heat Produced by Different Lights.—In the issue of the *Journal of Gas Lighting* for September 8th, 1896 (page 417), reference was made to some experiments which had been carried out by Herr Peukert, of Hanover, with the view of ascertaining the quantity of heat emitted by electric lamps in the space of one hour. The following results of his investigations (which, as will be seen, embraced other light-giving materials) have been published in the *Zeitschrift für Electrotechnik*:—

TABLE LXVI.

	Units of heat.
Incandescent lamps—	
Siemens and Halske	427
Edison	355
Swan	430
Bernstein	153
Gas—	
Siemens' Regenerative burner	1,500
Argand	4,860
Two-hole burner	12,150
Petroleum—	
Round burner	3,360
Small flat burner	7,200
Solar oil—	
Schuster's and Bauer's lamps	3,360
Small flat burner	7,200
Rape oil—	
Carcel lamp	4,200
Reading lamp	6,800
Candles—	
Paraffin	9,200
Spermaceti	7,960
Wax	7,960
Stearine	8,940
Tallow	9,700

With regard to the value of the Bernstein lamp, M. Peukert thinks that it is possibly too low, owing to the fact that in the measurements, losses of heat were not absolutely guarded against. The construction of the lamp was such that it could not be entirely immersed in the water employed to determine the heat given out.

CHAPTER XXVIII.

PRACTICAL EXAMPLES OF ELECTRIC LIGHTING ON DIRECT AND ALTERNATING-CURRENT SYSTEMS.

As indicating the advance which has been made in lighting by means of electricity, and the present position of that system, the following particulars of typical installations have been kindly supplied by the various authorities mentioned:—

I.—Stockton-on-Tees.

The three-wire continuous-current system has been very successfully adopted at Stockton-on-Tees. The contractors for the whole of the installation in this station were the Brush Electrical Engineering Company, Limited. The standard pressure of supply to consumers is 230 volts, with 460 volts between the outer conductors. The boiler-house contains three Galloway boilers, 28ft. long by 7ft. 6in. wide; a Green's economiser, the scraper gear of which is driven by an electric motor through worm gearing; and two feed pumps, with a duplicate range of feed pipes for supplying the boilers with water from a tank placed overhead.

The generating machinery consists of three Universal engines coupled to continuous-current generators of the Brush Company's standard pattern. One of the engines is coupled to two 25-kilowatt two-pole generators arranged to supply either side of the three-wire system with a variation in pressure of from 230 to 260 volts. It is largely used to balance the two sides of the three-wire system as well as to charge the cells. The other two engines are each coupled to 150-kilowatt six-pole generators supplying at 460-520 volts on to the outer conductor of the three-wire system, and are of the usual pattern made by the Brush Company for light and traction purposes.

There is a double balancer fixed close to the switchboard, which can be used either to balance the three-wire system or as a booster for assisting in charging the cells, or both together. The switchboard contains the usual panels, cell regulators, and feeder cables.

The dynamos are protected by automatic switches and the feeders by fuses, which prevent damage being done by excessive current. There are three miles of distribution, and one and a-quarter miles of feeder cables.

II.—WATFORD.

As an example of the equipment of an electricity supply station on the high-tension alternate-current system, we give the following brief description of the Watford station:—The contract for the whole of this plant, except the switchboard and cables, was assigned to the Brush Company, who also supplied and fixed the transformers and street boxes.

There are two boilers of the Babcock and Wilcox type, each capable of evaporating 6000 lb. of water per hour. The feed-water is supplied from a well and pumped into a large feed tank, that can also be filled from the town mains. The lift pump, as well as the feed pumps, is of the Smith-Vaile type, and the latter are in duplicate with duplicate feed pipes, and so arranged as to supply the boilers either direct from the tank or through the economiser. The economiser scrapers are worked by means of belting driven by a single-phase alternate-current motor of the Kolben type.

The generating plant consists of two 150-kilowatt sets, and one 30-kilowatt set, the latter being principally used for the station day-load. The sets comprise Raworth's Universal engines, direct-coupled to Brush inductor-type alternators. The engines of the two larger sets are of 250 indicated horse-power, and run at 300 revolutions per minute; they are fitted with automatic expansion governors. The alternators are designed for a pressure of 2200 volts at a frequency of 50 alternations per second.

The switchboard is of the Cowan steel type, and is divided into panels, each complete in itself, of enamelled slate. The bus bars are mounted on porcelain insulators behind the board, and all high-tension parts are absolutely protected, and accidental contact with them is impossible.

There are five and a-half miles of high-pressure feeder mains, which are of the concentric type, with the "outer" earthed, and work at 2000 volts; and twenty-five miles of low-pressure mains for public lighting, of which nineteen miles are of the twin type and six and a-quarter miles concentric. The low-pressure private lighting cables are concentric and five miles in length, forming a network with disconnecting joint boxes.

There are ten street transformer boxes for private lighting, transforming from 2000 to 200 volts; also six transformers for public lighting, transforming from 2000 to 400 volts, the distribution in each case being on the two-wire system.

With the exception of four arc lamps in the Market-place, the whole of the public lighting is done with incandescent lamps of 8 to 16 candle-power, arranged two in series across the 400-volt mains. The old gas lamps have in most cases been adapted by placing the electric lamps in the gas lanterns.

Mr. W. C. C. Hawtayne, of Queen-street Place, prepared the scheme, and acted as consulting engineer to the Watford Urban District Council throughout the contract.

GLOUCESTER MUNICIPAL ELECTRICITY WORKS.

These were designed by and carried out under the direction of Mr. Robert Hammond, M. Inst. C.E., &c., Consulting Engineer.

The Boiler House.—The boiler house contains four Lancashire boilers, three by Yates and Thom, of Blackburn, and one by Tinkers. Each of the former boilers is

30ft. long by 8ft. in diameter, capable of evaporating 6500 lb. of steam per hour. The latter is 30ft. by 8ft. 6in., and evaporates 8000 lb. They are made of steel throughout, and are constructed for a working pressure of 160 lb. per square inch. The shells are composed of seven rings, each made from one plate $\frac{13}{16}$in. thick. The boilers are fitted with Proctor's mechanical stokers. The dampers in the side flues are worked from the front end of the boilers, the balance weights being arranged to work in guides, which are graduated to show the opening in inches and feet. Water is fed into the boilers by a compound double-acting ram pump, made by Evans, of Wolverhampton, with an injector as stand-by; and the feed-water can be passed directly into the boilers, or alternately through a feed-heater and a Green's economiser, containing 96 tubes. A Bruce-Peebles 5-kilowatt shunt-wound motor placed outside the pump house drives the shafting for the mechanical stokers and the scrapers for the economiser. The main steam and feed pipes are of lap-welded steel, and the whole of the pipework was entrusted to Messrs. Ashton, Frost and Co., Ltd., Blackburn.

The Engine House Plant.—The original generating plant consisted of two combined sets. The larger set is composed of a triple-expansion engine, with one high and two intermediate cylinders placed above three low-pressure cylinders, working on cranks set 120° apart. The engine runs at a speed of 350 revolutions per minute, and is designed to give 500 indicated horse-power, with 160 lb. steam pressure. To this engine are coupled two Silvertown dynamos, the two being capable of giving an output of 300 kilowatts at any pressure between 440 and 500 volts. The dynamos are of the single horseshoe type, with drum bar armatures and shunt-wound magnets.

The smaller engine is a two-crank compound engine, with one high and one low-pressure cylinder, working on cranks set 180° apart, the steam being distributed by a single piston slide valve of special design placed between them. This engine runs at a speed of 380 revolutions per minute, and will give 250 indicated horse-power, with 130 lb. of steam. The engine drives two Silvertown dynamos having a combined capacity of 150 kilowatts, at any pressure from 440 to 550 volts, these machines being of the same type as those of the larger set. The engines, which were made by Messrs. Belliss and Morcom, Ltd., of Birmingham, are fitted with their patent system of forced lubrication. In this system a small pump worked off the main shaft supplies oil under pressure to a series of pipes which convey the oil to each bearing and ensure every working part being thoroughly lubricated. By this means the engines are enabled to make uninterrupted runs for long periods without any undue consumption of oil. The design, truth of workmanship, and accuracy of adjustment of the plants are of the highest class, and permit of the engines running quietly and without trouble at the high speed at which they work. Since the opening, an additional 300-kilowatt set of plant (Willans 500 horse-power and Mather and Platt dynamo) has been erected and is now at work, thus making the total capacity of the generators 750 kilowatts.

A booster is placed in the engine-room, and provides the necessary additional pressure for charging the battery. It consists of two single horseshoe undertype machines coupled together and mounted on the same bed-plate. One machine runs as a motor, and obtains current from the bus bars at 220 to 250 volts. It drives the other machine, which is a generator, and is designed to give a current of 100 ampères, at any pressure from 20 to 150 volts when running at a speed of about 780 revolutions.

In the condenser pit, the Blake and Knowles Steam Pump Company have erected three of their world-wide known jet condensing plants. Each of these is capable of dealing easily with 10,000 lb. of steam per hour, and of maintaining a vacuum of 26in. under all normal conditions of atmospheric pressure.

An overhead travelling crane spans the engine-room. It was made by Messrs. Spencer, of Hollinwood, and will lift a weight of 10 tons.

The Switch Gear.—On a gallery running along one side of the engine-room is placed the switchboard. It is composed of nine enamelled slate slabs fixed in a wrought iron frame, which rests on a plinth of glazed bricks. The slates are insulated from the iron frame by ebonite bushes and washers, and the uprights of the framework are hidden by a polished brass beading, which gives a very neat appearance to the board.

The switchboard is divided into three parts: the positive on the right, the booster and battery switches and instruments being in the centre, and the negative on the left. On the positive side are mounted the two minimum automatic cut-outs, shunt regulating switches, and shunt breaking switches for the dynamos, as well as their duplex fuses and two-way switches. In circuit with each dynamo is a Crompton shunted type ammeter, and a Crompton dead beat voltmeter is common to the two machines, the switch being placed below the voltmeter. At the top of the board are placed the six sets of feeder gear, which consists of an ammeter, a two-way switch with a quick-break action for disconnecting the circuit, and a duplex fuse. The negative side of the board is similar in every respect. The centre panel contains all the switches for operating the booster. Above these are placed hand wheels, which are geared to the battery switches, which are placed in the battery-room over the switchboard. Each hand wheel is surrounded by the numbers of the contacts on the battery switch, and the gear is so arranged that for each complete turn of the wheel the battery switch is moved on to a new contact, the number of which is indicated by a pointer moving to the corresponding number on the front of the board.

In circuit with the earth connection from the middle wire an automatic device has been fixed off the board. It is manufactured by Messrs. Crompton and Co., and is of the same construction as their well-known type of automatic cut-out. It is so arranged that as soon as the earth current exceeds 10 ampères, the ammeter is short-circuited, leaving a direct connection from the middle wire to earth. There is an interlocking arrangement on the switch which prevents the ammeter being put into circuit until the earth current has again fallen below 10 ampères. The dynamos and the booster are connected to the board by means of india-rubber lead-covered cables drawn into Doulton casing; and the battery is coupled up by ½in. copper rods run on insulators, which are suspended on wrought iron straps from the roof.

The whole of the switchboard work and the cable and copper connections have been carried out by Messrs. Crompton and Co., of Chelmsford.

The Battery.—The battery consists of 280 K.W.S. type cells manufactured by the Electrical Power Storage Company, Limited, and is capable of maintaining a discharge of 80 ampères continually for 10 hours. The containing boxes are of wood, lead-lined, each cell containing thirty plates separated by glass tubes held in places at the top and bottom; and the cells are placed on two-tier stands with iron standards and wood bearers. The approximate weight of each cell, complete with acid, is 435 lb.

The Mains.—Callender's Cable and Construction Company were entrusted with this important part of the work, the mains being laid on the "solid" system. Briefly, this method may be described as follows:—In the trench square cast iron troughs are laid, into which, at intervals of about a foot, are placed wooden bridge pieces for supporting the cable. A clearance all round the cable is thus provided, so that when bitumen is poured into the trough it flows all round the cable. Over the troughs are laid cast iron covers. For the private supply the electricity is conveyed from the generating works to various parts of the city by six "feeder" cables, which, as their title implies, feed the network of cable that distributes the current amongst the consumers. The five principal "feeders" are of ·4 square inch section, the other being ·25 square inch. By the side of each feeder a three-core $\frac{7}{20}$ "pilot" cable, lead-sheathed and armoured, is laid direct in the earth, and runs from each feeding point to the main switchboard at the generating works. The distributing mains form a complete network of cables of various sizes, and are joined up to the feeders in Callender's disconnecting boxes. From the distributors service lines are run to each consumer. All the feeders and distributors are triple-concentric, lead-sheathed cables, which are further protected by the bitumen compound in the cast iron troughs.

The cable used for conveying the energy to the public street lamps is a $\frac{7}{16}$ single lead-sheathed conductor laid direct in the ground. Each section of the public lighting cable is connected at suitable points to the network.

The total amount of cable laid up to the present is as follows:—

	Miles.
Feeder cables	8¾
Pilot cables	3¾
Distributor cables	12½
Public lamp cables	3¾
Total	28¾

Considerable extensions have been made to the mains since the opening of the works.

The Public Lighting.—At the present there are 44 arc lamps in use for the street lighting, these being grouped in four series of nine lamps each, and two of four lamps, and supplied with electrical energy from the distributing network. The lamps are the Brockie-Pell single carbon type, and are erected on posts supplied by Messrs. Hardy and Padmore, of Worcester. Each lamp is provided with an automatic switch, which inserts a substitutional resistance if the circuit in the lamp be broken. For trimming and repairs the lamps are lowered by means of a winch fitted in the base of the pillars.

System of Charging.—After very careful consideration, the Corporation decided to adopt a sliding-scale system,

TABLE LXVII.

The following Table gives a Useful Comparison of the Cost of Electric Light and Gas in Gloucester.

Class of premises.	Number of hours lamps are used.		Average charge per unit consumed during the year.	Annual cost of electric lamps and ordinary gas burners giving 8 c.p.		Annual saving on each 8 c.p. lamp by use of electricity.
	Average per day.	Total per annum.		Electric lamp.	Ordinary gas burner with gas at 2s. 6d. per 1000 cu. ft.	
			d.	s. d.	s. d.	s. d.
Offices, &c.	1	365	7	6 4	3 6	—
Early closing shops... ...	2	730	4¾	8 8	7 1	—
Other shops	3	1095	3·8	10 4	10 11	0 7
Dwelling-houses, &c. ...	4	1460	3·4	12 2	14 6	2 4
Hotels, restaurants, and public-houses	5	1825	3·1	14 2	18 3	4 1
Clubs and billiard rooms	6	2190	2·9	15 11	21 10	5 11
	7	2555	2·78	17 9	25 7	7 10
	8	2920	2·68	19 7	29 2	9 7
Outside lamps, dark business premises and basements	11	4015	2·50	24 11	40 1	15 2
	24	8760	2·23	48 10	87 5	38 7

N.B.—The above figures do not include the cost of renewing lamps, but a lamp (costing 1s.) will burn about 2¾ hours a day for a year. On the other hand, no allowance has been made in respect of the great saving that may be effected by the use of suitable switching arrangements for turning off the light when not required, or in respect of the periodical saving in the cost of decorating premises and other advantages resulting from the use of electricity.

whereby the price of electricity to any consumer will be regulated by the length of time during which the supply is used. The scale of charges has been fixed as follows (since revised by reducing 7d. to 6d.):—

Sevenpence per unit: For any number of units up to the equivalent of 100 hours' use per quarter of the maximum demand recorded by the demand indicator. (N.B.—By "maximum demand" is meant the largest quantity of electrical energy *in actual use at some particular time* during the quarter.)

Twopence per unit: For all consumption during the quarter beyond the above. The object of this sliding scale of charges is to provide for the payment by each consumer of the due proportion of the charges which are involved in laying down and always keeping ready the necessary plant for the supply of the full amount of electrical energy which the consumer may at any time demand.

For motive power the following rates have been adopted: —4½d. per unit for any number of units up to the equivalent of 100 hours' use per quarter of the maximum demand recorded by the demand indicator; 1½d. per unit for all consumption during the quarter beyond the above. That this is an extremely favourable rate to the consumer will be seen from the following table:—

TABLE LXVIII.

	d.
For a use of 1 hour per day of the maximum demand, the average price per unit will be	4·5
For a use of 2 hours ditto ditto	3·15
For a use of 4 hours ditto ditto	2·32
For a use of 6 hours ditto ditto	2·05
For a use of 12 hours ditto ditto	1·77

The following particulars of the first eight and a-half months of working will be of interest:—

Number of 8 candle-power lamps connected at 31st March last	14,008
Number of units sold during eight and a-half months	177,834

Price charged during that period:—

For lighting, 7d. per unit for the first 100 hours of the maximum demand per quarter, 2d. per unit for all further consumption.

For power and heat, 4½d. per unit for the first 100 hours of the maximum demand per quarter, and 1½d. per unit for all further consumption.

The average price for the eight and a-half months works out as follows:—

Private lighting and power supply... ... ... 4·30d. per unit.

The financial results were as follows:—

Total revenue for eight and a-half months ...	£2760
Costs of working...	£1536
Gross profit...	£1360
Interest and sinking fund...	£1423
Deficit for eight and a-half months	£63

For the first few months' working of a new concern this is a highly satisfactory result.

The costs of working are as follows:—

	£	Per unit.
Coal	642	·87d.
Oil, waste, water, and engine-room stores...	57	·07d.
Wages of workmen	310	·42d.
Repairs and maintenance	134	·18d.
Rent, rates, and taxes	125	·17d.
Management expenses	268	·36d.
Total	1536	2·07d.

BRISTOL.

Historical Note.—Bristol was one of the earliest of British towns to take active steps to secure rights to work an electrical undertaking under municipal control. In 1883 a Provisional Order was obtained from the Board of Trade under the Electric Lighting Act of 1882. For some years, however, no further steps were taken, Mr. W. H. Preece (now Sir William Preece), the Consulting Engineer called in by the Committee to advise, recommending "a waiting policy" until schemes for generation and distribution had been further developed and tried.

In December, 1891, Mr. Preece presented a report recommending the outlay of £66,000 upon the equipment of a complete system for the supply of 20,000 incandescent lamps (*i.e.*, 10,000 of 16 c.p.) and 100 arc lamps. A site for the generating station was obtained at Temple Back.

In October, 1892, Mr. H. Faraday Proctor, the City Electrical Engineer, was appointed to supervise the general arrangement of the works, and manage them when laid down.

The supply of electricity to private consumers was commenced in August, 1893, at the date of the opening of the Bristol Exhibition, and the public street arc lamps were first lighted in November of the same year. By the end of 1893 there were connected nearly 8000 lamps, or about 40 per cent. of the total number originally contemplated in the scheme. Up to this period 20 miles of cable had been laid, ten sub-stations equipped, and 120 consumers connected, the capital outlay being about £80,000 (including the value of plant purchased but not paid for).

In 1894 the plant capacity was increased by two-thirds, a small gas engine and alternator which had been put in to run the light load during the small hours of the morning and the day, being displaced, the rapid increase in the demand for current having rendered this plant too small for beneficial use. Further additions have been made to the generating plant every year.

In 1896 a general scheme was prepared and passed for the extension of the buildings and machinery, and also the mains for private supply and for public street lighting by arc lamps. The general arrangement of the extensions was carried out on similar lines to the original, but larger machines were put in, each unit of plant (*i.e.*, engine and alternating-current generator combined), giving double the output of the largest machine hitherto used. Five more Lancashire boilers, fitted with automatic mechanical stokers, were put down. In this extension electricity was adopted for driving all the auxiliary plant, such as boiler feed pumps, mechanical stokers, circulating pumps, &c.

In 1898 a still further extension of the plant was arranged, including two Babcock and Wilcox water-tube boilers, and considerable developments and improvements were made in the switchboards from time to time.

Owing to the limited space available at Temple Back, and the very rapid increase in the demand for electricity, it became necessary to consider the best means of arranging for the ultimate requirements, or at any rate to meet the demand for many years to come.

The site selected and purchased for the new electricity works is situated on the Feeder Road; it is bounded by the Feeder Road and Canal, one of the Bedminster collieries, a branch line of the Great Western Railway, and by vacant land; it is about ten acres in extent, and is within a reasonable distance from all parts of the City for the distribution of electrical energy.

The schemes for the extensions were prepared by the Engineers of the Electricity Department. The excavation for the foundations for these works was commenced on November 12th, 1900. The foundations for the main buildings were practically completed about the end of April, 1901. The erection of the superstructure and the machinery were carried on simultaneously, and the steam pressure was first raised in the boilers on December 23rd, 1901, that is to say, only thirteen months after the commencement of the excavation for the foundation contract.

Generators.—In the engine-room, which is 150ft. long by 47ft. wide and 40ft. high to the springing of the roof, there are at present placed two 745-kilowatt steam alternators, each capable of an emergency load of 920 kilowatts; in other words, each of these machines at its emergency load would supply sufficient energy to keep alight 30,666 8 candle-power lamps. There are also two 165-kilowatt steam dynamos, intended for driving the works power; that is to say, for supplying the energy to the numerous motors used for driving auxiliary plant in the present instalment and future extension of the works.

Engines.—The engines are all of the well-known Willans central valve make, and are single-acting triple-expansion engines, the larger ones having three lines and the smaller ones two lines of cylinders. The high speed, besides giving great steadiness in driving, concentrating great power in a small space and saving weight enormously, specially adapts the Willans engine for the direct driving of dynamos or other high-speed machinery, and is an important factor in steam economy.

Alternators.—Each of the larger engines is direct coupled to a Siemens " Copper-type " alternator, running at a speed of 224 revolutions per minute, generating electricity at a pressure of about 2000 volts. The exciters for the alternators are also of Messrs. Siemens Bros.' make.

Dynamos.—The smaller engines are direct-coupled to Siemens two-pole compound-wound dynamos, generating continuous current at a pressure of 500 volts.

Motors.—The motors for driving the auxiliary plant throughout the works are of Messrs. Siemens Bros.' 4D type.

Switchboards.—The switchboard gallery is at a height of 12ft. above the engine-room floor, the room underneath being used for the machine resistances and other apparata in connection with the switchboard. The switchboards are of the Ferranti type, and are built into the wall. They are composed entirely of non-inflammable material, being specially designed to avoid risk of either fire or personal injury to the operators. Heavy slate panels are fixed horizontally, and grouted into the wall. Between these main slates, and sliding into grooves in them, are arranged a number of vertical division slates, about ½in. thick, dividing the whole base into a number of distinct compartments. The switches, instruments, bus-bars, &c.,

are mounted in such a way that each appliance and each conductor is separated by some insulating material, each fitting being mounted in an entirely separate compartment. The cables, run from machines, are sealed in receivers fixed to the bottom of the board, and in the case of the alternating current board, one conductor is connected to the earth bar—also fixed to the bottom slate—the other being joined to the fuse panel contacts. Each machine and circuit panel consists of an oil-brake fuse, with duplicate contacts, a high-tension spring "oil-brake" switch, high-tension ammeter and contacts, and bus-bar fittings. All instruments, fuses, bus-bar links, &c., may be quickly removed without danger while the board is alive, and the board having no back avoids the usual tangle of cables, thus minimising the danger of fire or accident. This is the same type of switchboard as that which is being installed by degrees at Temple Back to take the place of the older form of switchboard.

Trunk Cables.—At these switchboards connections are made by means of "trunk" mains with the plant at Temple Back, it being the intention to run the whole of the plant, for the time being at any rate, in parallel, the energy generated at the Avonbank Works being transmitted by means of these trunk mains to Temple Back Works for distribution over the city. The mains at present laid are three in number—two conductor, concentric, paper insulated —of Messrs. Siemens Bros.' make.

Generators.—In the engine-room there are eighteen Willans engines, working at a steam pressure of 125 lb. per square inch, driving alternators and dynamos, the former for general lighting purposes and the latter for street arc lighting and for power supply.

Systems of Supply.—The distribution of energy is carried out on the three following systems:—(1) High-pressure alternating current at 2000 volts. (2) Direct current at 600 volts for arc lighting. (3) Direct current on the three-wire system at 250 or 500 volts.

(1) *High-pressure Alternating-current Supply.*—The current is taken from the central station by means of cables direct to distributing sub-stations at various central points, and is there transformed from 2000 volts to 105 or 210 volts, at which pressure the energy is delivered to the consumers.

The high-pressure alternating-current system was adopted on account of the very large area over which the energy has to be supplied. It is neither safe nor permissible to supply the public generally at a high pressure, but, on the other hand, it is not economical to distribute a low-pressure current at a great distance from the point where the energy is generated. It was, therefore, desirable to generate the current at a high pressure and transform it down to a lower and safer pressure at numerous local centres for distribution Under existing circumstances alternating current is more suitable than direct current, since alternating current can be transformed by apparata having no moving parts and not requiring constant attention. The transformers in Bristol receive their supply of current at a pressure of 2000 volts, and they reduce this to a pressure of 105 or 210 volts, that is to say, in the ratio of about 20 to 1 or 10 to 1; at the same time the quantity of current is amplified in the same ratio. For each ampère of current delivered to the high tension, or primary side of a transformer, 20 or 10 ampères respectively are delivered from the low-tension or secondary side. These apparata, together with the switches, automatic cut-outs, and other appliances, are placed in sub-stations, which are usually situated under the footways or roadways.

The sub-station, which is situated under the roadway at the junction of Whiteladies' Road with Queen's Road, contains such apparata, but in addition thereto it is used as the distributing centre for the whole of Clifton and Redland; that is to say, the main or trunk high-tension cables from Temple Back are laid thereto, and sub-high-tension cables are taken therefrom to all the different sub-stations in the before-mentioned neighbourhoods. The necessary fuses and other safety appliances required for the controlling of these feeders are contained in this distributing station.

The trunk feeder cables for the Clifton and Redland street arc-lighting circuits are similarly treated in this distributing station. In other words, this distributing station, in relation to Temple Back, performs the same functions for the north-western portion of the city as the Temple Back station will perform, in relation to the new Avonbank Electricity Works, for the city generally. The energy is transmitted from Avonbank to Temple Back by trunk feeder cables for distribution to other feeder cables connected with the different sub-stations in the city. There are in all at the present time 55 sub-stations, the dimensions of the smallest standard size of sub-station being 10ft. long, 6ft. 6in. wide, and 6ft. 6in. high.

The cables used for feeding the sub-stations with high-pressure current are two conductor concentric cables insulated with impregnated fibre or paper, protected from moisture by the formation of a lead tube, at great pressure, round the outside of the insulation at the time that the cable is manufactured; this tube is further protected by a covering of yarn or jute, which is then served over with two continuous tapes of steel wound on spirally, so that the outer tape overlaps the joint of the inner one. This steel sheathing is served with an impregnated braiding to prevent corrosion. Such cables are laid direct in the ground at the depth of about 18in., preferably under the footways. They are then covered over with bricks, simply as a caution to workmen who may at any time be disturbing the soil in the neighbourhood.

2. *Direct Current at* 600 *Volts for Arc Lighting.*—The whole of the street arc-lighting is arranged on what is technically known as the multiple series system. An arc lamp such as is used in Bristol requires a current of about 10 ampères at a pressure of about 50 volts. The arc lamps are arranged in circuits, twelve lamps being placed on each

circuit. A cable with one conductor is laid up to the first lamp on the circuit, such cable being supplied with 10 ampères of current only; the whole of this current passes through the first lamp and is carried by an extension of the cable to the next lamp, through which it also passes, and so on till it has passed through all the twelve lamps forming the circuit; to the other terminal of the last lamp the return cable is connected. Since each lamp requires a pressure of about 50 volts, and the cable is supplied at a pressure of 600 volts, the twelve lamps thus absorb the whole of the energy delivered to this cable. The first ninety-six street arc lamps erected in Bristol were on this system.

In the later extensions of arc lighting the system has been slightly revised, inasmuch as two-wire concentric cables have been used to supply the circuits, these being in some instances fed by six conductor cables, as, for instance, at the Victoria Rooms distributing station.

The arc lamps are all of the Brockie Pell type, the older lamps having top and bottom carbons of the same diameter. There are two pairs of carbons in each lamp, such being necessary to allow of the lamp burning throughout the whole of a winter night without being re-carboned. When the required hours of burning are less than in mid-winter the short lengths of carbon which are often left over are inserted in that side of the lamp which first comes into operation, so that these lengths may be burnt up; after which that side of the lamp "cuts out," and the side containing the other carbons automatically comes into operation. At the moment of change over, and for a short while afterwards, until the new carbons have become incandescent and burnt to their proper shape at the points, the lighting is liable to be somewhat erratic, as is the case immediately after the lamps are first lighted.

3. *Direct Current on the Three-wire System at* 250 *or* 500 *Volts for Motor Power.*—Since numerous applications were received for electricity for driving machinery in different

parts of the city, it was deemed advisable to inaugurate a supply of direct current for such purposes, since direct-current motors are more suitable for driving some classes of machinery than those supplied with alternating current. Mains for supplying this class of energy have been laid in the principal manufacturing districts in the central portions of the city, and are being also extended to some of the outlying districts as the demand arises.

Some of the advantages of motor driving for machinery in factories may be summarised as follows:—(1) Saving in cost of power. (2) Flexibility of the system. (3) Increased output at the same or less cost. (4) Greater immunity from serious breakdown.

1. *Saving in Cost of Power.*—In considering the question of the electric driving of machinery, the saving in cost of power is too often looked upon as the only advantage to be gained, and is treated lightly, because the whole cost of power in a manufactory often forms a very small proportion of the total cost of production. It must, however, in such instances, be evident that if advantages are gained under other heads leading to a substantial increase of output and diminished cost of production, they are of much greater importance than the saving in cost of power. Owing to the great diversity in the arrangement of different factories, it is impossible to lay down any fixed laws by which saving can be effected under the above heading. In the case of a large, well-arranged, one-storey factory with one engine of economical design, suitably placed for driving several main lines of shafting, the actual saving in cost, though considerable, will not be so great as in a factory extended from time to time, consisting of two or more storeys or separate buildings, each having one or more small and less economical engines supplied with steam, either by long lengths of steam piping from a central boiler plant or from separate boiler plant with correspondingly decreased efficiency.

The saving to be effected in the cost of power may be considered under four heads:—(*a*) Cost of power production. (*b*) Distribution. (*c*) Maintenance, repairs and attendance. (*d*) Intermittent working.

(*a*) In the majority of factories (particularly is this so in small ones) the cost of power production is very considerable, owing to the impossibility of obtaining small engines which are economical in their working, and which, due to the lack of skilled attention, are allowed to become yet less efficient as time passes. If an engine is allowed to work without periodical "indicating" and careful examination, its efficiency may fall considerably without such becoming apparent, whereas in the case of an electric motor, the efficiency cannot fall or change in any way after it is once in proper working condition.

(*b*) In order to appreciate the saving under the head of distribution, it is necessary to consider the circumstances in each individual case. With a system of steam driving, losses occur due to radiation from the steam pipes, energy absorbed in shafting, belting, bevel or worm gear, &c.; such losses are practically constant at all loads, and bear a very much higher percentage to the useful power when only partial load is on the plant. All these losses, with the exception of the loss due to radiation from the steam pipes, are common to gas-driven plant. In the case of an electrical system the distribution by means of cables and wires takes the place of the steam pipes, main belts, main shafts and gear, perhaps leaving in some few cases short lengths of shaft. In the majority of instances the motor can be directly coupled to the machine to be driven, thus entirely obviating the necessity for any shafting. The losses in wires and cables at top load are exceedingly small in a well-designed system; at times, other than the maximum load, the losses are practically negligible even should the system be indifferently arranged. The saving to be obtained by electric driving under this head alone will probably be fully 5 to 10 per cent., at full load, over a carefully-designed steam plant, and has proved to be much greater at lower loads. Indeed, in some instances, the saving has amounted to 60 or 70 per cent.

(*c*) There is a saving in maintenance, repairs and attendance, owing to the greatly diminished quantity of shafting, belting, and the absence of steam joints. Since the action of a motor is entirely a rotary one, the wear is practically nil, there being no reciprocating parts or even rubbing surfaces, other than the two bearings and the brushes. The commutator is the only part of the motor that requires more than casual attention, but if due care is taken to keep it clean and the brushes are properly set, no trouble is experienced, the whole work of examining and setting the brush gear may be easily carried out by one man in half an hour in the case of a large motor, or in less time in that of a small one. The lubrication is automatic.

(*d*) The rapidity and ease with which an electric motor is started and stopped, results in a very great diminution in the amount of energy used, since each motor will be stopped the instant the machinery driven by it is idle, and will cease to absorb energy until such machine is again required. The change over from steam to electrical driving can be effected by such stages as will allow the work of a factory to proceed practically without interruption, and will also allow of a thorough practical trial of the newer system of driving, under working conditions without a change of the entire system.

2. *Flexibility of the System.*—The use of separate motors for large machines or for groups of small machines enable these latter to be placed in the most suitable positions for the convenient handling of the material to be worked, irrespective of the position or direction of the line shafts. The advantages to be gained by the use of portable or semi-portable machines is very great, it often being more convenient to take a machine to its work rather than move the material to the machine. A great range of speed can can be obtained economically by a suitable means of control.

The flexibility of the system is also a great advantage in case of extensions to the works, more especially when the supply of power is obtained from an independent source, such as a Municipal Electricity Department, in which case no anxiety need be felt with regard to an increase of generating plant, with its attendant capital outlay rendered necessary by an increased demand.

3. *Increased Output at the Same or Less Cost.*—It is more difficult to appreciate the manner in which an increased output may be obtained, but there has been considerable testimony by those who have adopted the system; not only has there resulted an increased output, but also a very important reduction in cost of labour in the handling of materials, due to the better arrangement of the original machinery and the utilisation of the space rendered vacant by the greater compactness of the plant. Such economy of space is considerable and important, especially where extensions of premises cannot be obtained.

As motor-driven machinery may be fixed in the most convenient positions, irrespective of the direction or speed of running, it is found that machinery can be better arranged, as regards economy of space, and in such a manner that the rehandling of materials is reduced to a minimum, whilst the absence of overhead shafting and belting, and of heavy timbering for carrying the same, allows of much better lighting and cleanliness generally, as well as freer space for the removal of bulky articles from one place to another. The floor space, which under other circumstances would be required for, say, a steam engine, may accommodate other plant, thus directly bringing about, though perhaps in a lesser degree, the increased output which would indirectly result from the above causes.

4. *Greater Immunity from Serious Breakdown.*—Immunity from breakdown is of great importance, since heavy loss and inconvenience occur should a large portion

or the whole of a "works" be stopped owing to a breakdown of the main engine. This risk is greatly minimised by the use of independent motors; in the event of a breakdown occurring on one, it only causes a stoppage of that portion of the plant which it drives. Such a motor may be replaced temporarily or otherwise at short notice. In practically every case the plant used by the Corporation for supplying energy is in duplicate; in self-contained factories the provision of ample spare engine power entails a large capital expenditure and the occupation of valuable space, which might be more advantageously dealt with. Great care should be exercised in the arrangement of motors for driving a factory, as the choice of a system with single motors driving separate machines or of group driving, that is to say, the driving of a few machines in immediate proximity by each motor, will depend upon individual circumstances. The cost of small motors (per horse-power of output) is considerably greater than that of larger motors, and their efficiency is not so high, yet it often happens that, for intermittent work, the installation of small motors is the more economical in the end. In most cases economy will result from the conversion to electric driving in any existing factory, whilst in the arrangement of many factories electric driving will be found to bring about most, if not all, of the advantages above enumerated.

Progress of the Undertaking.—An indication of the progress of the undertaking, and at the same time showing that the rate of progress is in no way diminishing, is shown by Table LXIX. It will be noted that the increase in the number of lamps connected has been greater during the year 1900-1 than in any previous year, the additions amounting to 21,799 lamps, the greatest number added hitherto having been 17,801 lamps, and for the current year this maximum rate of increase was nearly maintained, being 19,400. The above figures apply to lighting alone. As there are many districts in which the

TABLE LXIX.—*Particulars of Undertaking.*

Reference No.		1 year to Dec., 1893.	1 year to Dec., 1894.	1 year to Dec., 1895.	1 year to Dec., 1896.	3 months to Mar., 25, 1897.	1 year to Mar. 25, 1898.	1 year to Mar. 25, 1899.	1 year to Mar. 25, 1900.	1 year to Mar. 25, 1901.	1 year to Mar. 25 1902.
1	Public lamps, number of arc lamps installed	90	97	99	105	105	105	304	308	310	310
2	„ „ incandescent „	—	—	—	—	—	3	3	3	9	9
3	„ „ equiv. in 30-watt lamps	1,500	1,616	1,650	1,750	1,750	1,778	5,094	5 161	5,241	5,241
	Motors on consumers' premises—										
4	Number installed*	—	—	2	2	2	7	15	32	98	150
5	Aggregate horse-power†	—	—	3·33	3·33	3·33	19·53	60·53	111·53	377·5‡	785‡
6	Equiv. in 30-watt lamps to date	—	—	83	83	83	486	1,504	2,770	9,389	19,520
7	Equiv. in 30-watt lamps added during year	—	—	83	—	—	403	1,018	1,266	6,619	10,131
	Lighting consumers' premises—										
8	Equiv. in 30-watt lamps added during year	7,903	6,627	9,433	12,253	2,537	10,478	17,801	16.154	21,799	19,400
9	Equiv. in 30-watt lamps to date	7,903	14,530	23,963	36,216	38,753	49,231	67,032	83,186	104,985	124,385
10	Total connection to date, equiv. in 30-watt lamps (sum of Nos. 3, 6, and 9)	9,403	16,146	25,696	38,049	40,586	51,495	73,630	91.117	119,615	149,146
11	Consumers connected at year's end, number	120	240	439	593	617	749	967	1,215	1,507	1,790
12	Capacity of alternating and direct-current machinery in 30-watt lamps	23,333	31,000	33,800	40,533	—	65,733	86,300	105,133	103,400	164,066
13	Capacity of alternating direct-current machinery in kilowatts	700	930	1,014	1,216	—	1,972	2,589	3,154	3,102	4,922
14	Maximum alternating and direct-current load during year in kilowatts	225·5	322	514·5	766	656	1,010	1,707	1.676	2,009	2,535
15	Load factor for the year	8·48 %	10·41 %	9·06 %	9·7 %	17·8 %	10·3 %	9·11 %	12·35 %	11·92 %	12·41 %
16	Miles of distributing cable laid	6·1‡	7·9	12·7	16·9	17·6	21·6	27·8	37·4	42·56	46·69
17	„ H.T. feeder „	6·96	11·45	12·8	15·6	16·9	21·8	25·54	36·2	48·77	52·92
18	„ arc light „	6·95	7	7	7	11·1	49·5	49·7	49·7	48·34	48·90
19	„ power feeder „	—	—	—	—	—	—	—	4·75	6·45	6·66
20	„ power distributor cable laid	—	—	—	—	—	—	—	·35	1·9	4·02
21	Total mileage of cable laid	20·01	26·35	32·5	39·5	45·6	92·9	103·04	128·4	148·02	159·19
22	Units sold to private consumers during year (lighting power)	53,829	143,106	251,708	483,527	188,357	743,163	1,033,324	1,330,670	1,587,951 128,261	1,965,794 310,054
23	Units sold for public lighting during year ...	10,019	150,417	156,593	167,231	47,607	167,725	329,462	481,841	475,347	480,776
24	Total units sold during year	63,848	293,523	408,301	650,758	235,964	910,888	1,362,786	1,812,511	2,191,559	2,756,624

* Motors only. † Inclusive of heating appliances. ‡ Approximately.

mains have not yet been laid, it may be hoped with confidence that the rate of progress will be maintained for many years to come, more especially since the use of electric radiators has quite recently come very much to the fore. The most rapid progress, however, is noticeable in connection with the motor load. During the first few years the prices charged for current used for motors were excessive, and retarded the progress, but the charges are now exceedingly low, as may be gathered from the rapidity with which the demand is now increasing.

The schedules of the terms upon which electricity is supplied under different conditions are given in Tables LXXI. and LXXII. Since one of the greatest factors in the cost of supplying electricity is that of meeting the capital expenditure, special terms have been arranged to give a preference to those consumers who use the energy during times when the machinery is not taxed to its greatest extent, as the revenue from such is not attended by any increase of capital for additional machinery. Lighting consumers, who use the energy during hours of daylight or after midnight, may obtain that energy at a cheaper rate than those who use it only after sunset.

Consumers, using electrical energy for motors or heating apparata are also supplied at specially low rates, since their use of the energy is quite irrespective of the hours of darkness. Their demand is spread over many hours per day, commencing about 6 a.m. and extending to 5 p.m. or 6 p.m. and even later throughout the whole year. The plant for generating such energy is therefore earning revenue during 8, 10, or even 12 hours per day, whereas, when supplying light alone, the demand, when averaged, only amounts to about two hours per day throughout the whole year.

The charge for current for power and heating purposes was reduced to 1¼d. per unit, less discount, on October 1st, 1900, since when the additional connections and applications for power have become very numerous.

The following table shows briefly the rate of progress:—

TABLE LXX.

Date.	Horse-power of motors on consumer's premises.
March 25th, 1898	19
„ 1899	60
„ 1900	111
„ 1901	377
February, 1902	719

In addition to the above, applications have been received for supply to 460 horse-power of machinery, which will be connected up within the next month or two, bringing up the total to 1179 horse-power.

Lighting Rates.—For electricity consumed between midnight and one hour before sunset, 3⅓d. per B.O.T. unit* ; for electricity consumed at other hours, 5d. per unit. Both rates subject to the following scale of discounts if payment is made within twenty-one days after the accounts are rendered:—

TABLE LXXI.

In March and December quarters, on accounts of not less than the following amounts.			In June and September quarters, on accounts of not less than the following amounts.			Discounts.
£	s.	d.	£	s.	d.	Per cent.
16	13	4	8	6	8	5
33	6	8	16	13	4	10
83	6	8	41	13	4	15
166	13	4	83	6	8	20
333	6	8	166	13	4	25
416	13	4	208	6	8	27½
500	0	0	250	0	0	30

Customers consuming current at two or more premises are allowed the rate of discount for the aggregate amount of their lighting accounts.

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* This rate of charge is only applicable where the consumer hires a special appliance, at the rate of 5s. per quarter, which appliance, by its automatic action, enables the current to be charged for at the reduced rate during the prescribed hours.

Rates for Power and Heating Purposes.—1½d. per unit, subject to the following scale of discounts, if payment be made within twenty-one days after the account is rendered:—

TABLE LXXII.

Amount of quarterly account.		Rate of discount.
	£.	Per cent.
Not less than	25	2
„	50	2½
„	75	3½
„	100	5
„	125	6
„	150	7½
„	160	8
„	170	8½
„	180	9
„	190	9½
„	200	10
„	220	10½
„	240	11
„	260	11½
„	280	12
„	300	12½
„	320	13
„	340	13½
„	360	14
„	380	14½
„	400	15
„	500	17½
„	600	20

NOTTINGHAM.

During the past seven years a striking development of the Nottingham electricity works has taken place. The original station has been doubled in size, and filled with plant having a capacity of 1600 kilowatts, while the pressure of supply has been raised to 200 volts; a new building has been added with a capacity of 4000 kilowatts, the whole of which is either installed or in course of delivery, and an entirely new station is about to be erected, having a capacity of more than 10,000 kilowatts.

The older portion of the station consists of a boiler-house 100ft. long by 47ft. wide, containing eight Lancashire boilers by Edwin Danks and Co. (Oldbury), Limited, and an engine-room 80ft. by 40ft. containing 14 Siemens-Willans steam dynamos of sizes from 50 to 250 kilowatts. The dynamos are of the two-pole drum type, with smooth-core armatures, and the engines are of Messrs. Willans and Robinson's standard patterns, the whole being characteristic of station practice prior to the introduction of large units. There is a three-wire switchboard at each end of the engine-room, both being connected together and to the lighting switchboard in the new engine-room.

The steam range forms a ring main, and is connected with the range in the new building.

The dynamos are all of Messrs. Siemens Bros.' multipolar type, driven by Willans three-crank compound engines; six sets are in full running order, one is now in course of erection, and two more are due for delivery. The first four sets installed are intended solely for light and power service. The engines are of Messrs. Willans and Robinson's standard 3S type, compound non-condensing, and run at a speed of 300 revolutions per minute, with a steam pressure of 160 lb. per square inch. They are controlled by throttle governors,and driven direct from the shaft. The dynamos are 8-polar, the field-magnets being of steel, cast in two parts with the division on the horizontal diameter. The magnet cores are cast with the frame, and are circular in section; they are shunt wound, and the polar extensions are bolted to the plane ends of the cores. The edges of the pole tips are double wedge-shaped, so that the polar arc is somewhat greater at the middle of the armature than at either end.

The armature has a toothed core, with a massive commutator, and weighs about 9 tons; this mass, revolving at 300 revolutions per minute, renders a fly-wheel superfluous, its place being taken by a comparatively light bearing wheel, which is combined with the flange coupling.

The commutator end bearing is provided with two oil rings, as well as an oil way for extra lubrication.

The brushes are of carbon, so mounted that each set can be raised from the commutator *en bloc* by means of a lever, and any one brush can readily be replaced or adjusted; the brush-holder carrier ring is supported on six rollers carried by the magnet frame, and is rotated with a tangent screw. The machines run without sparking at loads much beyond their rated current, and have given great satisfaction in all respects. Their normal output is 875 ampères at 400—460 volts, but they are frequently run at 950 ampères, 430 volts.

The shunt rheostat is mounted at the side of the machine, and is furnished with two step switches, one for large variations of resistance, the other for the finer adjustment, so as to obtain a wide range with very small steps.

The main terminals of the machine are situated at the lowest point of the frame, and are boxed in; a short stairway on each sides provides access to them and to the underside of the commutator.

From the generators, cables are taken through ducts to a subway which runs along the whole length of the engine-room, and thence to the lighting switchboard.

The lighting switchboard consists of five panels of enamelled slate, fitted with apparatus for controlling six feeders and six dynamos on the three-wire system. There are three bus bars traversing the whole length of the back of the board. Two of these are connected respectively with the two switchboards in the other engine-room, so that it is possible to maintain three different station pressures, should this be necessary, or to run all the dynamos in parallel. Each three-wire feeder has a 650 ampère meter and duplex fuse on each pole, and is connected with a vertical plug bar on each side of the system; the middle wire is coupled to the neutral bar through a 300-ampère meter and fuse. Each dynamo is in circuit with a 1200-ampère meter, minimum current cut-out and fuse, and is coupled to + and − vertical plug bars. There are also two dynamo voltmeters of the Weston pattern, and on the centre panel are three voltmeter plug boards, an earth-wire switch and fuse, and earth current ammeter. Above the board are two station voltmeters reading to 275 volts. The dynamo cables are brought directly up the back of the board, while the feeders pass up the opposite side of a subway, overhead, and down the board to their terminals, so that a clear passage is left behind the switchboard.

The whole of this apparatus, with the exception of the two voltmeters mentioned above, is of Messrs. Siemens Bros.' make. The instruments are of the moving coil type.

No provision is made on this board for balancing, as is done on the older boards.

The feeders and distributing cables are all of Messrs. Callender's manufacture, the earlier ones insulated with bitumen and drawn into bitumen casing, while some of the later ones are armoured and laid direct. No failures have occurred on any of the cables during the six years that the station has been in operation, with the exception of those caused by external injury.

The distributing network is abundantly provided with disconnecting boxes, also of Messrs. Callender's make.

During the summer of 1899 the system was changed over to 200 + 200 volts. Practically no trouble was experienced with objecting consumers, though, as in all such cases, some little difficulty was occasioned by the lack of a satisfactory 200-volt arc lamp.

There are now over 1500 consumers, with a connection equivalent to 127,000 8-candle power lamps, in addition to a total motor load of 600 horse-power. As the population of Nottingham is upwards of 250,000, there is ample scope for future development.

The tramway generating sets are generally similar to the lighting sets; the engines, however, are provided with automatic variable cut-off governors in addition to the throttle governor, so as to secure the maximum of efficiency and regularity with the fluctuating load of the tramways. The dynamos, also, are compound wound; this is neatly accomplished by winding a small series coil on each magnet core, apart from the shunt coil, and joining all the series coils in parallel by means of a ring of light copper bars at either end of the poles. By this means the handling of heavy conductors is avoided.

When nine cars were running the tachometer showed no variation greater than five revolutions per minute, which is less than 2 per cent., and there was no other indication of load on the machine. The economy in floor space and foundations inherent to the high-speed type of plant needs no demonstration.

There are two tramway generating sets in full running order, and a third is now in course of erection.

The traction switchboard is of white marble, with ten panels, and provides for three dynamos, six feeders, and the Board of Trade instruments. Each of the dynamo panels is equipped with a large automatic circuit-breaker, a 1000 ampère meter, main positive switch, shunt switch, and rheostat. Each feeder panel bears an automatic circuit-breaker, Elliott recording ammeter reading to 300 ampères, single-pole switch and fuse. The circuit breakers are of simple construction, the tripping solenoid in the dynamo circuit consisting of a mere kink in the heavy copper conductor; the circuit is broken on carbon plates with a long break. To restore the circuit after a cut-out, a long lever is provided, extending downwards to a convenient position for handling, and the breaker can be tripped at any time by means of a small trigger. The fuses in the feeder circuits consist of four wires in parallel, laid in grooves in a slate slab about 1ft. long.

The Board of Trade panel bears the usual Weston ammeters for earth return current and leakage test, recording earth current ammeter, and recording voltmeter for the line pressure reading from 350 to 650 volts. There are also four recording voltmeters for the drop of pressure in the rails, reading to 10 volts. The indication of the one at present in use averages only 3 or 4 volts. The negative and equaliser switches are mounted together on the frames of the generators. Behind the board are three Siemens and Halske watt-hour meters in series with the dynamos.

The whole of the switchboard, with the exception of the recording instruments, was manufactured by Messrs. Siemens Bros. and Co.

The Author is indebted to the General Electric Company (1900), Limited, for the following illustrations of the Fulham, Ilford, and Wigan Electricity Works. The descriptions of the two former are condensed by permission from very full accounts of those works which appeared in the *Electrical Review* of February 15th and June 7th, 1901, respectively; and that of the Wigan works from the *Electrical Engineer* on February 1st, 1901, to the editors of which papers the author desires to express his acknowledgments.

FULHAM.

In 1895, the Borough of Fulham appointed Mr. F. H. Medhurst to report as to the erection of electricity works combined with a refuse destructor, and in accordance with his recommendations it was decided to apply for an electric lighting Order, which was obtained in 1897, and in 1898 Mr. Medhurst was instructed to prepare the necessary plans and specifications for a combined scheme, to be erected on a riverside site, which the Vestry had already acquired.

In view of the growing demand throughout the country for electric light and power, the capacity of the station was increased beyond that originally proposed, and it will now supply a total of 30,000 8-candle-power lamps connected to the mains, exclusive of spare plant.

The capital outlay amounts to over £100,000, the following contracts being let for the work :—

Buildings, comprising destructor house, engine-room, offices, and transformer chambers, also a small building for public disinfecting purposes, F. G. Minter, Westminster	**£22,970**
Refuse destructor, steam-raising plant, inclined roadway, and chimney shaft, Horsfall Destructor Company	**16,760**
Generating plant, including steam pipes, condensing plant, mains, &c., and apparatus for the above-mentioned disinfector building, General Electric Company, Limited, of London and Manchester ...	**46,000**

Additional contracts for the supply of coal-handling plant, meters, well-sinking, extra foundations, and engineering expenses increase the total to £108,000.

The general arrangement of the buildings will be seen in the plan shown in Fig. 200.

Substantial construction and due provision for light and ventilation have been aimed at, with considerable success. Externally the buildings are of red brick, with relieving bands of white Suffolk brick. In addition to the usual offices, a testing-room is provided on the first floor, and on the ground floor there are stores, a meter-testing room, workshops for light work and repairs, water-softening and filtering room, with the well-pump driving gear. Beneath this block of offices is also the pump-room, both the latter rooms being reached from the engine-room. Access to the offices is from outside.

The destructor and boiler-house is a lofty building, 35ft. high to the springing of the roof, 137ft. in length, and 87ft. wide. It contains twelve destructor cells, arranged in two groups of six each on either side of six Babcock and Wilcox boilers, and are capable of efficiently destroying 120 tons of refuse in twenty-four hours.

Over the boiler-firing floor, and extending from end to end of the building. is the tipping floor, which is arranged to allow of the storage of a considerable quantity of refuse, so that the working of the plant may be continued without interruption. Access to the tipping floor is obtained by means of an inclined roadway, having a gradient of about

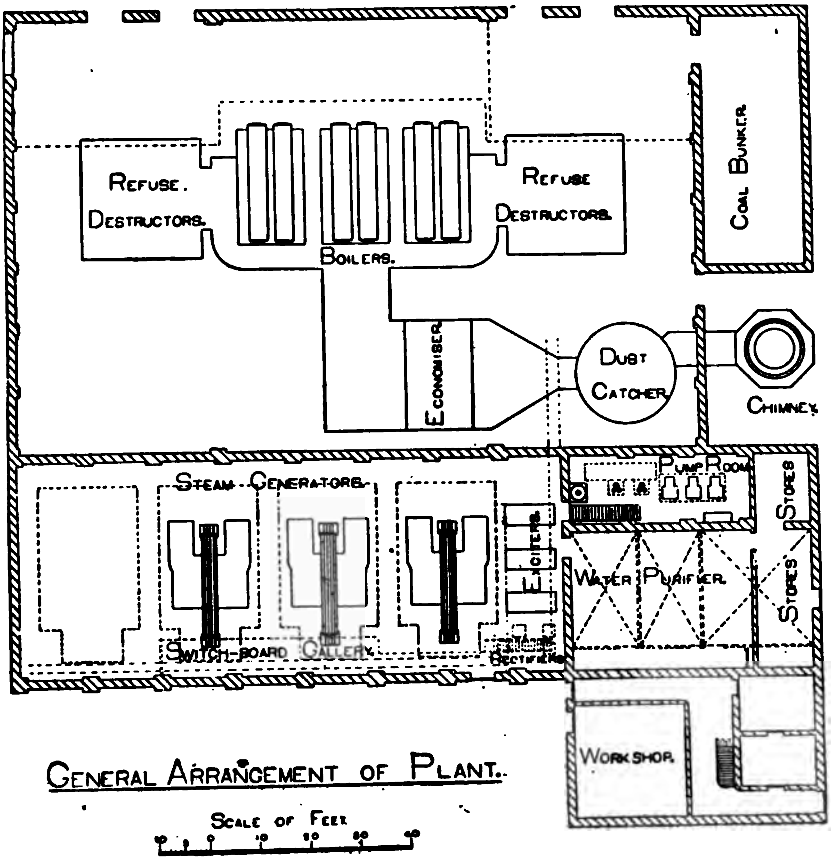

Fig. 200.

1 in 14, at the foot of which there is a weighbridge and house.

The engineer estimates that about 40,000 tons of refuse will be passed through the destructor per annum, and places

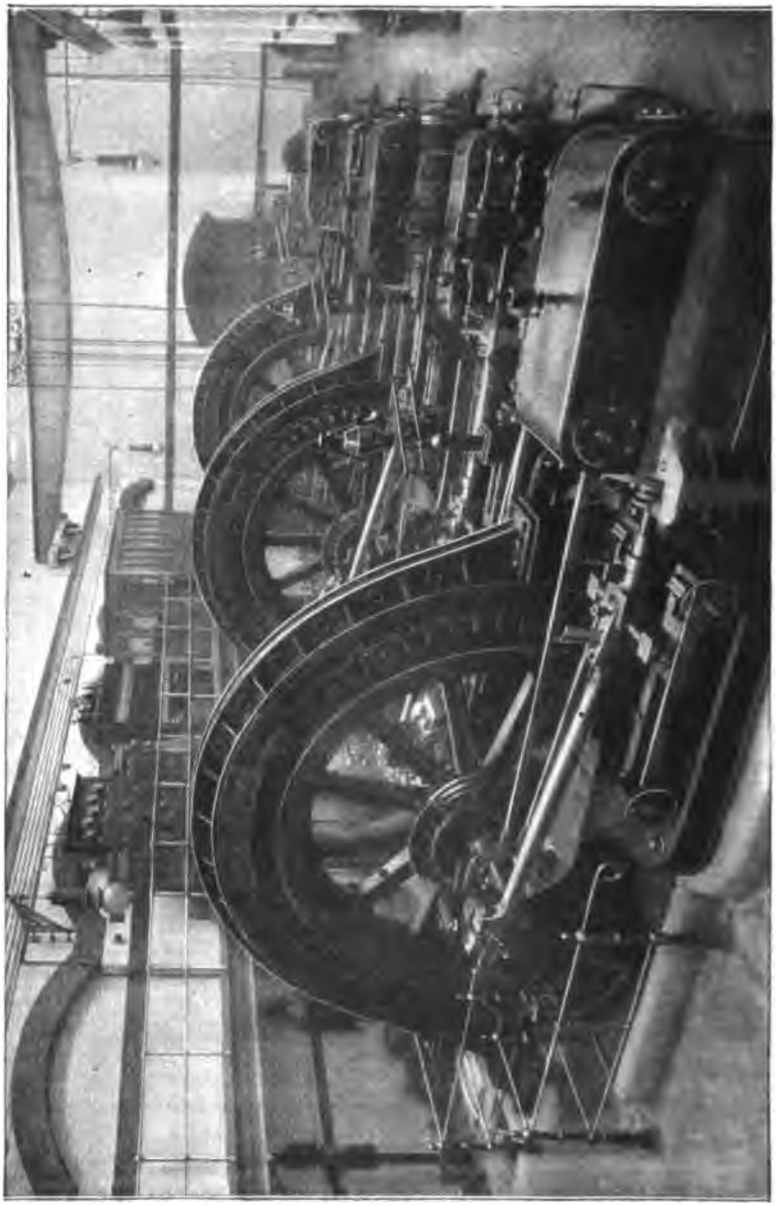

Fig. 201.—FULHAM—GENERAL VIEW OF ENGINE ROOM.

its calorific value at one-twentieth that of good steam coal. The Borough Council, therefore, expects to save the cost of 2000 tons of coal per annum.

A gallery runs round two sides of the room and carries the main switchboards and a switchboard attendant's office, space being left at one end of the room for an additional engine and dynamo. Two entrances to the destructor house are provided from the engine-room, one from the gallery and one from the floor, and these are carefully protected by double doors and glazed screens with the object of excluding dust.

The steam alternators are three in number, each set consisting of a two-phase generator of the fly-wheel type coupled direct to a horizontal compound condensing engine. The engines are of the low-speed Corliss type, made by Messrs. J. Musgrave and Sons, Limited, of Bolton, and each is capable of giving 450 brake horse-power when supplied with steam at a pressure of 130 lb. per square inch at the engine stop valve, and with a vacuum of 24in. of mercury in the exhaust pipe.

The governor is capable of controlling the speed of the engine within 3 per cent. from no load to full load, and is provided with means of adjustment to vary the speed 5 per cent. about the mean speed whilst running.

The three two-phase generators were constructed by the General Electric Company, Limited, at their Manchester works. Each generator (Fig. 202) is capable of giving a normal output of 300 kilowatts, each of the two sets of coils being capable of giving 150 kilowatts at all pressures from 2800 to 3000 volts at the terminals of the machines. The machines will also give an overload of 330 kilowatts continuously for two hours. The speed is 93·7 revolutions per minute, and the frequency 50 cycles per second.

The energy stored in the fly-wheel when running at its normal speed is 1,800,000 foot-pounds.

The field magnet poles with their windings are fixed on the periphery of the fly-wheel. The poles are laminated,

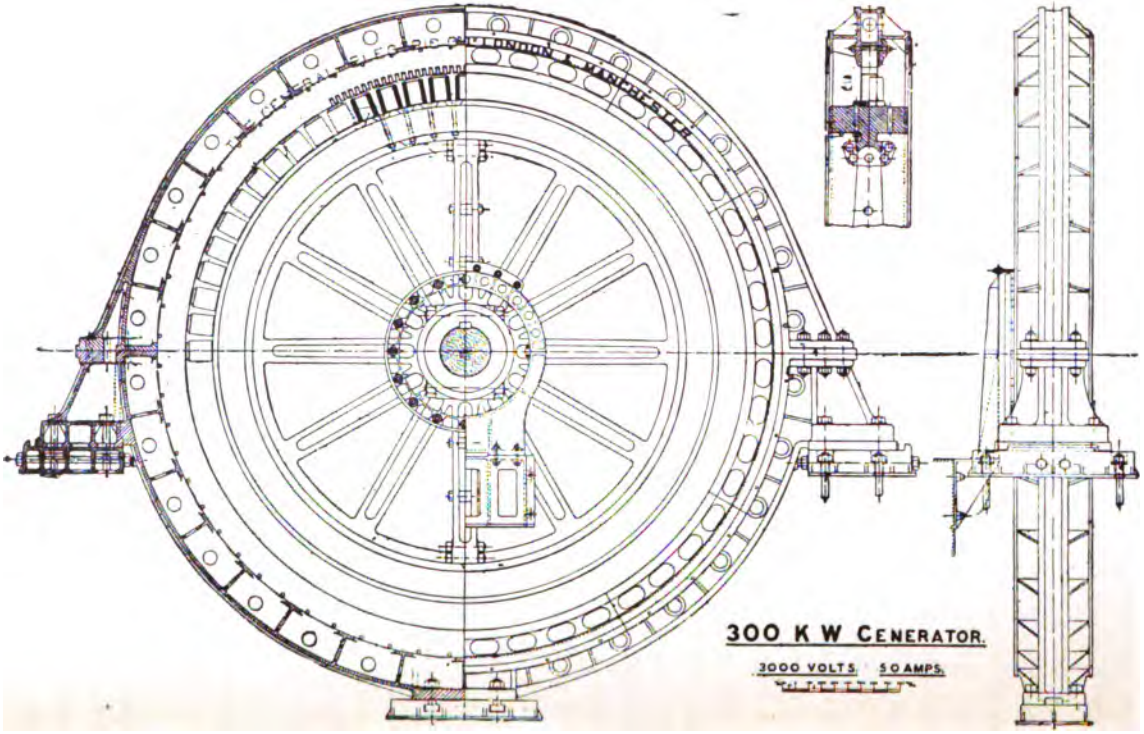
The General Electric Co. London & Manchester
300 K W Cenerator.
3000 Volts. 50 Amps.

Fig. 202.

riveted together, and fixed to the fly-wheel rim by means of steel wedges, the latter being securely fastened to the fly-wheel by strong bolts passing through its rim.

There are 64 laminated poles on each fly-wheel, wound with round copper wire, the exciting current being brought to them through two slip rings. The diameter over the poles is about 14ft. The necessary current for exciting the field coils is obtained from the continuous-current dynamos driven by high-speed engines mentioned below.

On the inner circumference of the stationary armature are spaced 256 slots which carry the copper windings. These windings are arranged to form two circuits, one for each phase. The windings of the one circuit have straight ends, whilst those for the other circuit have bent ends, as is the usual practice. The insulation between the coils and the iron frame is efficiently effected by mica tubes, and the coils are fastened securely in the slots by means of strong fibre wedges.

The four ends of the two series of windings are brought out to terminals, from which the current is carried to the switchboard for distribution to the various circuits.

There are three continuous-current dynamos (Fig. 203), which were also made by the General Electric Company, Ltd., for exciting and other purposes. Each is capable of giving an output of 600 ampères at 100 to 110 volts, at a speed of 460 revolutions per minute, and each is direct-coupled on one bed-plate to a high-speed enclosed-type compound engine of Messrs. Musgrave's make. They supply not only the necessary current for exciting the field magnet circuits of the three large generators, but also the various electric motors which are used for driving the condensing plant, economisers, and stokers. They also supply the necessary power for lighting the buildings and inclined roadway by arc and incandescent lamps. Either of the three dynamos is, of course, far more than capable of supplying the current required for the three generators. The dynamos are shunt-wound, having four poles with cast steel yokes, whilst the armatures are of the slotted type, with former-wound coils placed in the slots. The commutator is built up of hard-drawn copper, fitted with carbon brushes, and conforms to the usual specification as to temperature and fixed position of brushes.

Three Ferranti rectifiers of the latest type are placed in one corner of the room, with provision for a fourth, for supplying the public lighting circuits. The switchboard in connection with these is fixed on the wall beside the rectifiers. It is arranged for three circuits, any one of which can be fed from any one of the rectifiers.

The switchboard (Fig. 204) for controlling the distributing circuits and alternators is fixed on a gallery 10ft. above the floor level, so as to enable the engineer in charge to have a full view of the machinery in operation below. The board, which is of the Ferranti type, is divided into fifteen panels, six of which are allotted to the generators, six to the feeders, two for the rectifiers, and one for a testing circuit.

The low-pressure board, which is also on the gallery, is provided with the usual instruments, switches, and shunt regulators for the three 60-kilowatt dynamos above mentioned, and with switches and fuses for controlling the various motors in the building and the lighting of the station.

All the principal connections between the switchboards and machines are run beneath the floor level, and are rubber insulated, and, in the case of the high-pressure cables, lead-covered.

With the exception of the offices, the cables for station lighting are carried in water-tight "Simplex" steel conduits. There are six distribution boards, to which the current is transmitted from the works lighting-board, which is placed under the switchboard gallery in the engine-room.

The cables for public and private lighting purposes were supplied by the British Insulated Wire Company, Limited, and are concentric, lead-covered, yarned outside, and compounded. They are drawn into Doulton conduits under the footpaths, and into cast iron pipes under roadways. At

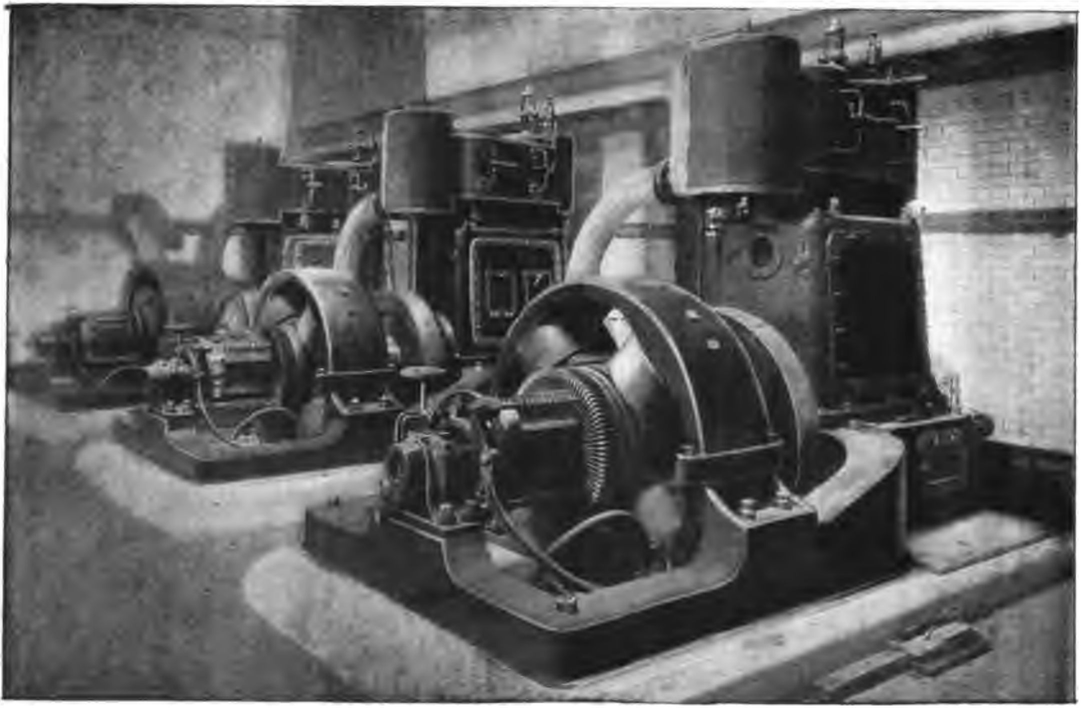

Fig. 203.—GENERAL ELECTRIC 60 K.W. DYNAMOS, AND MUSGRAVE HIGH-SPEED ENGINES

road crossings, however, wrought iron pipes, embedded in concrete, have been used, special reducing pieces of Doulton ware being employed for gradually changing the shape of the ducts from the square form of the Doulton conduit to the round form of the iron pipes. High-pressure feeders for both phases run from the generating station to the sub-stations, where the pressure is reduced from 2800 volts to 200 volts by stationary transformers; two-wire distributors radiate from the sub-stations, the two phases being run on either side of the street. The two phases will therefore be available everywhere where power is required for motors.

In addition to the above, two circuits of single cable run through the principal streets for public arc-lighting, which is described later on.

There are at present five sub-stations, each of which contains two 50-kilowatt transformers, one for each phase. The high-pressure windings on these transformers are connected up to the feeders through quick-break fly-off switches and fuses, while the low-pressure sides are connected up to the distributors through removable spring contact fuses.

The switching arrangements, as well as the transformers, are placed in water-tight cases; all ironwork is earthed, and a Cardew earthing device is fitted to each transformer. Due provision has been made for ventilating the sub-stations, which are lighted with incandescent lamps supplied from the low-pressure bars in the switch boxes. The chambers are all lined throughout with white glazed bricks.

With the exception of the refuse destructors and Babcock-Wilcox boilers, which were supplied under the Horsfall Company's contract, and the artesian well by Messrs. Potter and Co. the General Electric Company, Limited, as contractors, have been responsible for the whole of the machinery and plant so far described.

The public lighting consists of eighty-six arc lamps, carried on posts of ornamental design bearing the borough arms, and run in two circuits with about half the number on each. The lamps are 12-ampère 32-hour double carbon lamps of the General Electric Company's standard type, fixed about 25ft. from the ground. Brackets are also provided on each post for two 32 candle-power incandescent lamps, which are automatically switched on when the arc lamps are switched off or fail.

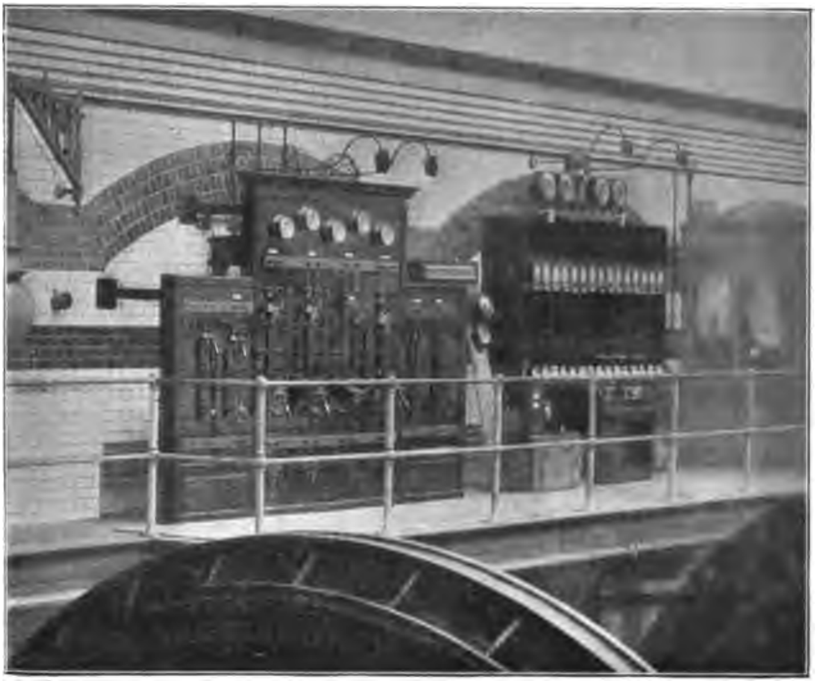

Fig. 204.

The Edmunds switch, recently re-designed and improved, is employed for this purpose, and is fixed in the base of each lamp-post.

The lamps are supplied with current through the rectifiers at the generating station, and the two circuits have been so arranged that, in the event of one circuit failing, the street lighting would only be reduced by one-half, and no district would be placed in darkness.

Private consumers are supplied at a pressure of 200 volts, while for motors both single-phase and two-phase supplies are provided.

The charge for lighting purposes is 5d. per unit, and for motive power 2½d. per unit during the hours of daylight. No meter rent will be charged.

No "free wiring" contract has been entered into, but it is satisfactory to note that the number of applications for supply already amount to an equivalent of some 10,000 8 candle-power lamps.

The writer acknowledges his indebtedness to Mr. Medhurst and to Mr. R. F. Ferguson, chief engineer and manager, as also to the various contractors, for the information embodied in the foregoing description.

ILFORD.

The Urban District Council of Ilford has for some time past been engaged upon a large combined electric lighting and traction scheme, for which Mr. W. C. Hawtayne has acted as consulting engineer, Mr. A. H. Shaw, A.M.I.E.E., being the resident electrical engineer. The lighting part of the undertaking, upon which some £60,000 have been expended, is now completed.

In the High-road the central arc lamp steel pillars carry the trolley cross-arms. The necessary switch gear for these columns is contained in the cast iron bases. Arc lamp columns are also in position in Cranbrook-road, these being of cast iron, and the lamps of 1500 candle-power. In all cases the arc pillars are fitted with a couple of incandescent lamps for switching on at midnight. The remaining streets in the lighting area are being rapidly provided with new lamp columns, equipped with incandescent electric lamps, and

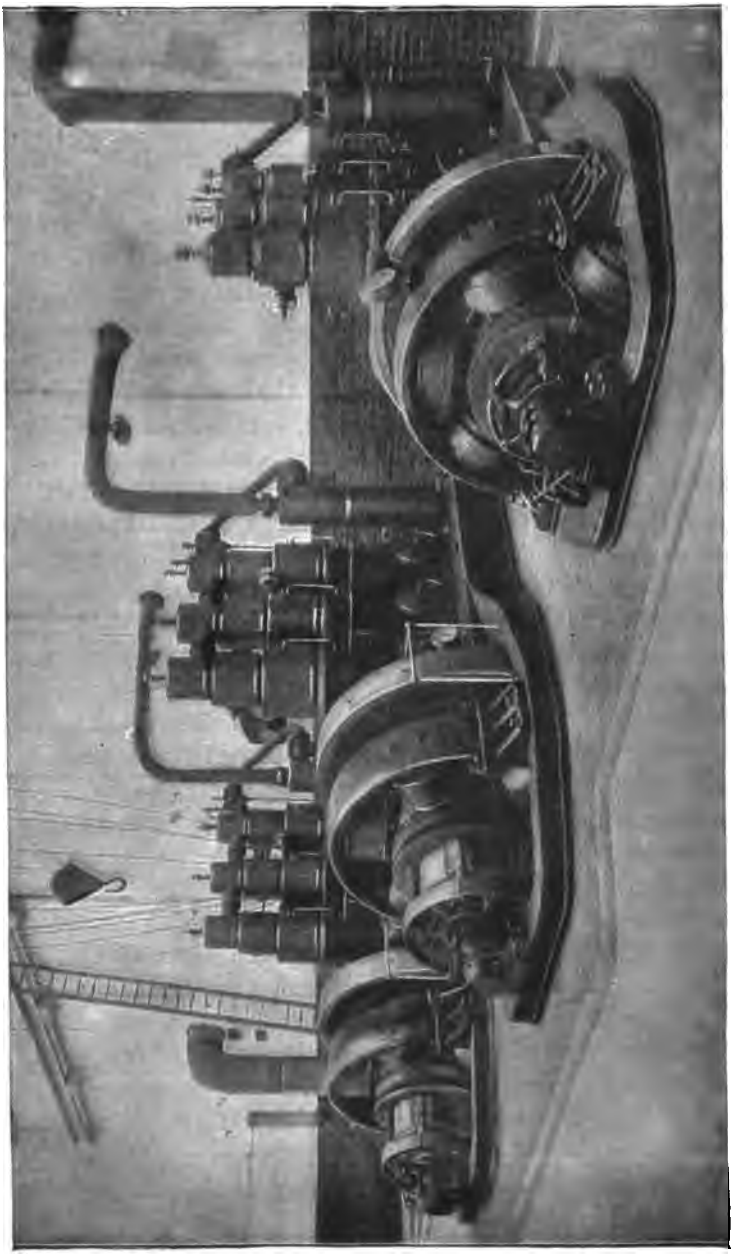

Fig. 205.—ILFORD ELECTRICITY WORKS—G. E. C.—WILLANS GENERATORS.

these will soon render the old gas lamps unnecessary. About 300 standards have been erected, and 36,000 yards of separate cables laid, enabling the whole of the lamps to be switched on or off from nine special pillars.

The position of the generating station is a little over a mile from the railway station and the central streets.

A very large plot of land has been purchased by the Council in order to accommodate lighting station, car sheds, workshops, &c. The buildings were designed by Mr. H. Shaw, the surveyor to the Council, and are light and roomy. Ample space is left in the engine and boiler-houses for additional machinery, all necessary safety, isolating, and other valves. Superheaters are provided with each boiler to ensure dry steam being supplied to the engines. There are two feed-pumps, each capable of supplying 2000 gallons of water per hour, one being a steam pump and the other a motor-driven pump, which can be worked from the storage battery if necessary. In the main flue leading to the chimney shaft, a Green's economiser is provided for raising the temperature of the feed-water by means of the waste gases escaping up the shaft. The steam pipes are of lap-welded mild steel with wrought steel flanges, and the exhaust pipes are of cast iron. A 2000 gallons wrought iron feed tank is also in use, and a well is now being sunk to provide the whole of the water required for the works.

There are two 200-kilowatt Byng-Hawkins dynamos and one 100-kilowatt ditto, supplied by the General Electric Company, Ltd., each being direct coupled to Willans enclosed high-speed engines (Fig. 205). The large sets run at 350 revolutions per minute, and the small one at 450 revolutions per minute. Each is capable of giving an emergency load of 25 per cent. in excess of the normal full load for one hour. In view of the running of electric tramways shortly, the dynamos are designed for either traction or lighting work. It is likely that additional sets of about 500 kilowatts will be installed when the tramway plant is put down.

A set of four balancing motor-generators and boosters, have also been furnished by the General Electric Company, Limited. Their object is to raise the pressure of the principal machines for charging the battery and for regulating pressure at all points on the supply mains. The battery is of the E.P.S. type, and has a capacity of 600 ampère-hours when discharged at the rate of 200 ampères for three hours.

The switchboard was designed by Messrs. Kelvin and James White, Limited, and is built up in panels of polished marble, and provided with all the makers' latest improvements in switches, cut-out, and regulating gear, and also a complete set of instruments, by which the output of each machine and the load on all parts of the system is measured and recorded.

The 15-ton overhead travelling crane erected in the engine-room was made by the Southgate Engineering Company.

The feeder cables run from the generating station out to a number of different points, and at the distributing points feeds the cables at the supply pressure, which is 230 volts at consumers' terminals. Pilot wires are laid from each feeding point to the station. The feeders, distributors, and service lines were all supplied by Messrs. W. T. Henley's Telegraph Works Company.

The feeder cables are armoured concentric cables laid direct in the ground; the distributing cables consist of three separate cables laid in a wooden trough filled in with bitumen.

The service cables consist of two or three cables bound together armoured and laid direct in the ground. Considerable additions have been made to the mains first provided, and the work now completed or contemplated includes approximately 17,800 yards of feeders, 17,800 yards of pilot wire, and 30,000 yards of distributors.

WIGAN.

The history of the electric lighting at Wigan goes back to 1890, when a Provisional Order was obtained from the Board of Trade. As was the case in a number of Orders granted in the earlier days, the town was anxious to keep the matter in their own hands, but had not sufficient confidence in the financial prospects of municipal electric lighting to carry out the scheme immediately their Order was obtained. The matter was considered again in 1896, and again in 1897, without any conclusion being come to.

In 1899 Mr. H. Collings Bishop was appointed to the post of electrical engineer, and promptly drafted a scheme for which powers were obtained to borrow £85,000, and the work was put in hand. The foundation stone of the buildings was laid on January 4th, 1900, and the works commenced to supply on December 17th. In order, however, to get together a certain number of consumers, a small temporary plant was put down, which supplied some 2000 8-candle-power lamps on the two-wire system. This plant was put to work by Mr. Bishop in December, 1899, and it has done much to enable the larger works to start with a good working load. The lamps were changed over from the two to a three-wire system as soon as the permanent works were completed.

Engines and dynamos.—The generating plant consists of four engines made by Messrs. Willans and Robinson, while the dynamos were supplied by the General Electric Company. The two large engines are of the Willans 3-I type, with three lines of cylinders and three cranks at right angles. Each of these engines is capable of developing 336 horse-power when running at a speed of 350 revolutions per minute with 160 lb. of steam at the stop valve. The two smaller engines indicate 240 horse-power at 380 revolutions. The above are at ordinary full load, as the engines will give an overload of 10 per cent. The governors are of the automatic expansion type, specially designed to enable the engines to respond quickly to the changes of load due to the tramways. The centrifugal governors actuate a relay which quickly moves the levers varying the cut-off in each line of cylinders.

The dynamos of the General Electric Company's six-pole type were all manufactured in their Manchester workshops. The duty of the larger dynamos is 420 ampères at any voltage from 460 to 500 on lighting load, and 500 to 550 volts, 300 ampères, on traction load. The smaller sets on lighting load are made for 460 to 500 volts, 300 ampères, and on traction load 500 to 550 volts, 215 ampères. These dynamos can be overloaded 10 per cent. on lighting load and 25 per cent. on traction load. The machines are over-compounded for traction work, the compounding being cut out for lighting service. The magnet frames of the generators are divided on the horizontal diameter, and the larger sets especially have very light fields and yokes, much resembling the American type. The pole-pieces and field coils are of cylindrical shape. The armatures are of the fly-wheel type, of large diameter, with slotted cores. The carbon brushes can be retained in a fixed position, and run sparklessly from no load to 25 per cent. overload.

Accumulators.—The battery was manufactured by the Electrical Power Storage Company, Limited, and consists of 280 cells in wood lead-lined boxes, each cell containing 15 plates erected on single-tier stands, and is capable of discharging at 75 ampères for ten hours, or 150 ampères for four hours, or 300 ampères for one hour, the final electromotive force at the end of any of these discharges not to be less than 525 volts. The first half of this battery was erected in a temporary battery room, but it has since been taken to the permanent electric lighting station, and the remaining half of the battery erected with it. There are two floor levels in the accumulator-room. The upper floor, which is only partially boarded over, is carried on iron girders, and is reached by a staircase from the ground floor. The cables to these accumulators are all of the rubber-covered type, and are laid in wooden casing which is filled up with bitumen. This gives a secure protection against the fumes from the acid. The charging of the battery is effected on somewhat novel lines. The procedure is as follows:—The battery is put across the 'bus bars, and the number of cells reduced until charging takes place. The cells so cut out of circuit are charged independently by a small motor-driven dynamo.

The arrangement of the subsidiary electrical apparatus in the station is decidedly novel. Mr. Bishop has elected to use only two-wire feeders throughout, and to distribute his balancing machines in various parts of the network. The third wire of the system is, however, brought back into the station, and two of these balancing machines are fixed in the main engine-room. Another point of novelty in central station work is that there is no provision made on the switchboard for supplying different voltages to different feeders. Thus there is only a pair of lighting 'bus bars—*i.e.*, one positive bar and one negative bar. In order, then, to be able to run at a common voltage in the station for both long and short feeders, provision is made for inserting boosters in the feeders which go to the more distant parts of the town. The balancing machines are of the General Electric Company's standard four-pole type, with a single field magnet and a double-wound armature. Each side is capable of transferring to the opposite side of the three-wire system 50 ampères at 230 volts. It will thus be seen that each of the balancers can compensate for 100 ampères out-of-balance current in the system. The machines run at a speed of 1100 revolutions per minute. Seven of these balancers are employed. Two of these are fixed in the central station, while the other five are placed in sub-stations constructed in various parts of the town. The boosters are placed in the engine-room, space having been found for them under the switchboard gallery. The dynamo is capable of passing a current of 500 volts, and of adding 20 volts to the electromotive force. The dynamo armature is duplex wound—that is to say, there are two distinct windings in parallel. This construction does much to enable the machine to run smoothly in spite of heavy currents being passed through its armature while the field is only a little excited. The field magnets of this booster dynamo are wound with a heavy conductor, through which the current to the feeder passes. In this way the electromotive force added is practically proportional to the current in the feeder, and also to the drop in the feeder. The regulation of the boosting is arranged for by inserting a low-resistance shunt across the terminals of the field winding. The switch gear for introducing the booster dynamo into a feeder circuit is a most ingenious one, and was designed for the purpose by the General Electric Company. It is so arranged that a series of resistances across the field-magnet winding that the armature is cut into the feeder circuit when it is generating only about two volts. The resistance is then increased until the required boosting voltage for the current going through the booster is obtained. The machine is then practically automatic, but it can be further regulated by altering the resistance in the shunt in the driving motor. This motor is supplied at 460 volts from the lighting 'bus bars, and its normal speed is 900 revolutions per minute. On trial it was found that this 10-kilowatt motor-driven booster had a combined efficiency of 74 per cent.

Mains.—All the cables, both for the feeders and distributors which were used at Wigan, were supplied by Messrs. W. T. Glover and Co., of Manchester. Five feeders are at present laid, each consisting of a concentric cable with a ½in. section of copper in each conductor. The three-wire distributing system for the lighting and power circuits consists of three conductors with sectional areas respectively of ·2, ·1, and ·2 square inch, the whole of which, for both lighting and traction, and also the distributors, are drawn into earthenware conduits of the Doulton type.

From various points on the system three-core pilot wires are brought back to the station, so that observations can be made on voltmeters there of the actual pressure on practically any part of the distributing system. These three-core pilot cables are also protected in the same way by being drawn into earthenware conduits.

The electrical energy sold for lighting is charged on the Brighton system, viz., 7d. per unit for the first hour per day average use of the maximum output demanded. Any energy consumed above this quantity is charged at 2d. per unit. The motors are also supplied on a sliding scale, which is as follows:—For an average use at full load of under one hour per day, 2d. per unit. Where the average use per day is between one hour and five hours, the charge is 1¾d., whereas the charge is still further reduced to 1d. per unit if the average use per day comes out between eight and twelve hours. The last stage in the scale provides that any consumer using his motors night and day throughout the year will only be charged ¾d. per unit. Some 6000 eight-candle-power lamps are now connected to the mains, and many more are applied for.

BATTERSEA.—ARC LAMPS.

The Angold Arc Lamps (Fig. 206).—The Angold arc lamps used in the Borough of Battersea were manufactured at the Manchester Works of the General Electric Company (1900), Limited. The lamps themselves and their accessories embody several novelties and improvements, partly suggested by the Consulting Engineers, Messrs. Kennedy and Jenkin, and partly the result of the firm's experience.

The lamps are divided into twenty-four circuits of ten in series, across the outers of the 460 volt lighting mains. They are of the 10 ampère, 18-hour single carbon Angold improved type, their general appearance being shown in Fig. 206.

The case is thoroughly weatherproof, each section fitting tightly into the one above; the leads pass into the lamp at the top through special leading-in tubes, and go right down to the terminals on the underside of the lamp base without breaking into the mechanism chamber. The latter is thus kept air-tight at the top, and the heated gases from the arc are prevented from passing through the chamber and depositing dust on the working parts. The leads can be disconnected and withdrawn without removing

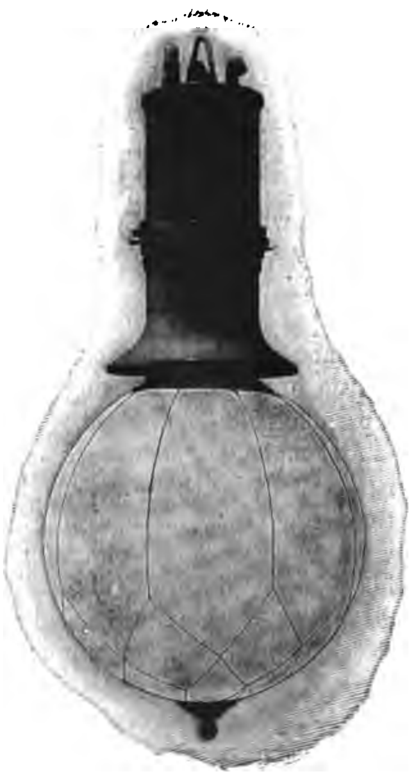

Fig 206.

the case of the lamp or unthreading them from the curved leading-in tubes. The case is entirely insulated from the current-carrying parts, and the globe slides on insulated rods, so that the lamp can quite safely be handled without danger from shocks.

The carbon holders are both on a ball-and-socket principle, so that they can be brought into line and afterwards clamped up, when they remain a fixture.

In order to reduce friction to a minimum, the solenoid cores and main levers are all arranged to work on knife edges. All moving parts are made as light as possible, and are checked with a strong dashpot in order to get a steady start with a minimum of line resistance. Side pull—due to mutual attraction and repulsion of the cores, and found in most arc lamps—is entirely eliminated, the magnetism from the cores being so controlled that a parallel field is produced.

Although many lamp makers have discarded rubber pads for the brake-band on account of the frequent regulation necessitated by the wear and consequent alteration of the "feeding point," and have used metal brakes which do not give such a steady feed as rubber does, the patent arrangement for compensating the wear of rubber as employed in these lamps, completely overcomes the above-mentioned trouble. A brake-drum carries a band furnished with rubber pads, one end of which is attached to a pulley controlled by a spiral spring in tension, and the other end is hooked on to the rocking frame controlled by the two cores. The tension of the spring keeps the brake in action, and compensates all the wear by taking up the slack and maintaining the position of the band relatively to the drum.

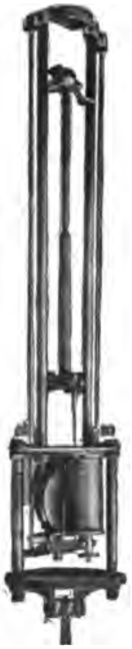

Fig. 207.

A pawl controlled by the rocking frame engages a toothed sector, concentric with the pulley to which the band is attached, at the "feeding point;" the pulley can now no longer take up the slack, and the brake is therefore released and the feeding takes place. When compensation takes place the pawl engages a different tooth, but always when the cores are at "feeding point;" hence the regulation remains constant.

It is claimed that these lamps possess the following important advantages:—

(1) A minimum of friction.

(2) Control by a rubber brake, ensuring a steady feed, which, with good carbons, is continuous.

(3) Compensation for wear of rubber brake.

(4) Good regulation; bad carbons causing not more than two volts variation.

(5) Good dashpot action, and light working parts, resulting in steady working with a minimum of line resistance.

The general appearance of the lamp with the case and globe off is shown by Fig. 207.

As already stated, the lamps burn ten in series across 460 volts, and as they each require 41 volts, only 50 volts are left for the line resistance. This is an unusually small proportion, being only about 11 per cent., whilst the usual practice is to absorb about 20 per cent. in the line resistance. Nevertheless, excellent results are obtained, 240 lamps lighting up without a hitch when the current is switched on for the first time.

Every post (Figs. 208 and 209) is fitted with an equivalent resistance, which is wound on the china bobbins and enclosed in a waterproof cover. The upper part of Fig. 210 shows the resistance with the cover off, and that of Fig. 211 with the cover on.

The automatic cut-out is fixed in an iron box immediately below the equivalent resistance; it was specially designed owing to the small line resistance used, because if all the equivalent resistances were thrown in parallel with the lamps, the current would be increased to 18 ampères, but the line

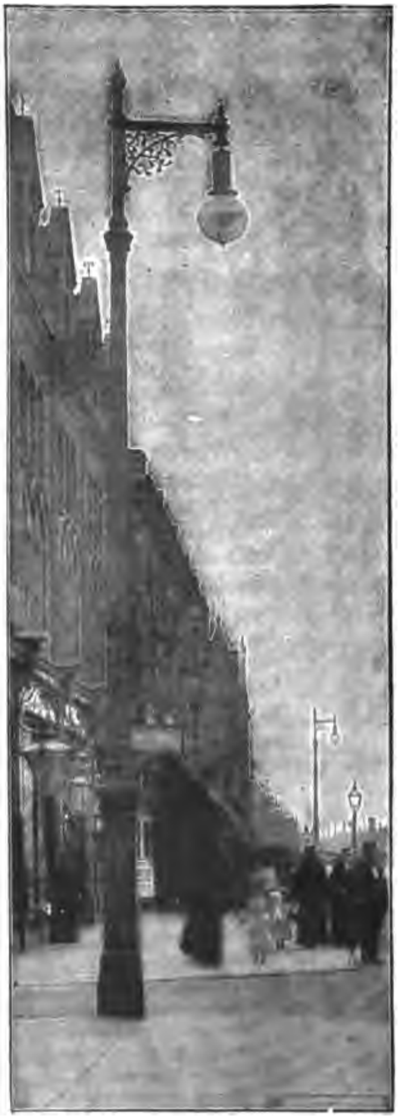

Fig. 208.

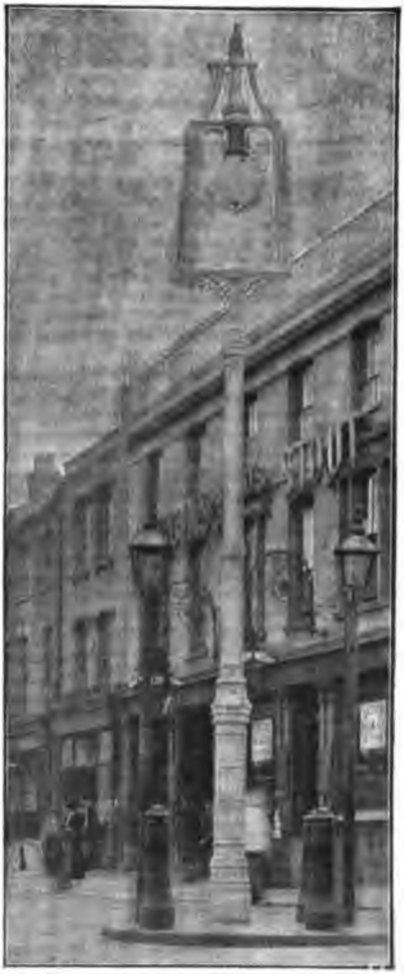

Fig 209.

resistance would take only 90 volts, and thus as much as 37 volts would be left for each paralleled set. The cut-outs take 70 volts to lift them, and therefore they could not all act at once in practice; but six or seven cut-outs can act together, and with the small line resistance the result is proportionally as above. Owing to the six or seven lamps getting practically normal voltage and current when this happens, great difficulty was experienced in designing the apparatus to cut-in again when the carbons came together, and at the same time leave sufficient pressure on the contacts when there are no carbons in the lamp. This was, however, successfully overcome, and a very

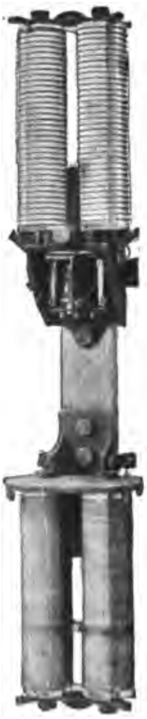

Fig. 210.

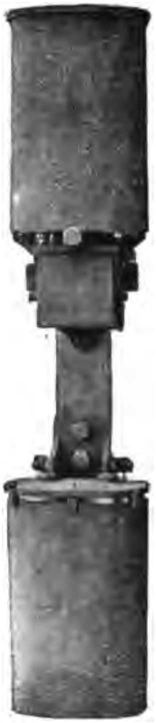

Fig. 211.

strong magnet is used, which leaves a good margin of pull on the armature, amply sufficient to depress eight separate contact pieces, which are connected in parallel and carry the current without any heating.

The second post in each series carries the variable line resistance, which is able to absorb a maximum of 600 watts. It is also wound on two bobbins, and shown on Figs. 210 and 211 at the bottom.

The two end posts of each series contain one single-pole switch and fuse, as shown on Fig. 212. The fuse is of the G.E.C. well-known H.V. type with lined fuse chamber, and is tested on a dead short circuit with 500 volts.

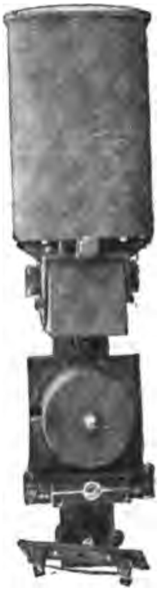

Fig. 212.

CROYDON.

The author is indebted to Mr. T. H. Minshall, Borough Electrical Engineer, for the following account of electrical street lighting at Croydon:—

The evolution of street lighting in districts where alternating current is supplied for private lighting has been extremely interesting. The earliest form of distribution for the latter consisted in placing a transformer in each house working, as a rule, at about 100 volts pressure, and for public lighting many stations adopted a similar system, using small transformers in the base of the posts. This, however, was not particularly satisfactory, or economical, and as the colour of the alternating arc left a good deal to be desired, many engineers preferred to use separate constant current arc lighting generators, a system which had been used in America for many years, and, as far as the quality of the light went, had been found very satisfactory; many of the stations in that country being exclusively devoted to public lighting. This, for some time, became standard practice, the principal developments being in the direction of increased size in arc lighters.

In England, however, the low efficiency of arc lighters driven by separate engines prevented their being much used, and the Ferranti rectifier, the introduction of which was the next important step, met with a good deal of success, the service, as far as the lamps were concerned, leaving little to be desired. Recently, however, both in England and America, the open lamp, whether alternating or direct, is being superseded by the enclosed lamp, and an enormous number of series alternating lamps worked from constant current transformers are being installed, this being quite the most popular form of lighting in America to-day, where open lamps are being everywhere replaced. By this means, the advantages of the series system are obtained without the use of special generating plant.

The first installation of public lighting at Croydon consisted of rectified lamps, of which sixty are still in use. In the outlying districts, however, it was found that the cost of laying mains all the way from the generating station was prohibitive, and recourse was had to alternating-current enclosed lamps.

Two systems of operating the latter are in use, one using series lamps, the other parallel ones; but both possess the great advantage of enabling the ordinary mains to be used for a greater number of hours per day, and hence producing a greater return for a given capital outlay.

The chief difficulty, viz., the colour, has been surmounted after a long and costly series of experiments, and it is now difficult for anyone but an expert to detect much difference between the direct and alternating lamps. The question of colour is a somewhat complex one, and before success was obtained, it was necessary to try a great variety of carbons, globes, and lengths of arc, &c.

Parallel System.—The system first adopted and still used in those parts of the district where a low-pressure network of sub-stations are provided, consisted in the use of lamps of the parallel type, which are run without any transformer or choking coil, thereby avoiding one of the most frequent causes of trouble.

At Croydon these lamps are made for 200 volts, and hence, with a 400-volt three-wire system, can be fed at very great distances from sub-stations. In some cases they are connected to the distributing mains, while in others, separate low-pressure cables are run back to the sub-stations, which enables a large number of lamps to be controlled by one man, and the current they take to be metered, as well as having other advantages.

Series System.—In certain districts, however, the nearest sub-station is at such a distance as to make the laying of 400-volt mains out of the question, and here a modified form of the series system, so popular in America, has been adopted. As the lamps are automatically compensated, it has not been found necessary to use constant-current transformers, the governing of the lamps being such as to prevent the total current increasing more than 5 per cent., even if half the circuit should become extinguished. It is advisable, however, to have a transformer separating the arc system from the main feeders to the generating station.

The relative advantages of the two systems depend on a variety of causes, but, as a rule, the series system will be found more economical in a straggling district.

Both systems possess the great advantage of improving the load factor or earning power for a given capital outlay. The general advantages of enclosed lamps are so well known that it is not necessary to dwell upon them, but it may be of interest to state that, in addition to the improved behaviour in bad weather, there has been found at Croydon a reduction of over 30 per cent. in the cost of carbons (although the very best qualities must be used), and of nearly 40 per cent. in the cost of trimming. On the other hand, there is the cost of inner globes, but now that the correct shape and quality of glass is used, the latter item is not serious, and is counterbalanced by the increased life of the outer globe due to less frequent removal for trimming purposes and the absence of breakages due to falling particles of hot carbon.

The standard distance of lamps is 60 yards, and whereever possible the trolley poles are used. When the latter (which are about 40 yards apart) are on both sides of the road, they are "staggered," and hence the use of alternate posts gives the required distance. Those on one side of the road are switched out at midnight, the remainder of the lamps, although 120 yards apart, being amply sufficient for the safety of the traffic after that time.

CHAPTER XXIX.

ACETYLENE.

DURING the last few years acetylene has taken a prominent place as an illuminant, the brilliance of the light produced by it, coupled with the convenience of its production, gradually winning its way into public favour.

In 1836 Edmund Davy, Professor of Chemistry to the Royal Dublin Society, described the gas acetylene at the meeting of the Society held in March in that year, and experimentally demonstrated some of its properties, and later in the same year he read a paper on it before the British Association at Bristol, the method described therein for the production of the gas being the ignition in an iron bottle of a mixture of calcined tartar and charcoal, with the result that potassium was isolated in addition to a black substance, which was easily decomposed by water, yielding a gas of great illuminating value when burned in contact with the atmosphere.

The importance of this discovery was clear to Davy's mind, his concluding remark being, "From the brilliancy with which the new gas burns in contact with the atmosphere it is, in the opinion of the author, admirably adapted for the purpose of artificial light, if it can be procured at a cheap rate."

The gas so produced has the composition C_2H_2, equal to 92·3 per cent. of carbon. In 1860 Berthelot showed that acetylene was formed during the decomposition of many organic substances by heat, and in 1862 he demonstrated the possibility of producing it in an atmosphere of hydrogen by passing electricity between carbon points

These and many other experiments on record, whilst interesting from the scientific standpoint, were not attended with practical results until 1889, when the process which has now enabled acetylene to be produced commercially was accidentally discovered by an American engineer, Mr. Thomas Leopold Willson, of Leaksville, in North Carolina, while experimenting with an electric furnace in connection with the production of aluminium. He was attempting to produce the metal calcium by the reduction of its oxide in the electric arc, and for this purpose fused together a mixture of powdered lime and anthracite. He was, however, disappointed to find that he had produced only a dark-coloured crystalline substance very like lava.

Regarding this as useless, he threw it into some water, which immediately began to bubble violently, an odour being produced, which at once attracted attention. A further quantity of the material was made, and on examination found to be carbide of calcium, the gas produced on its immersion in water being pure acetylene.

In 1892 Willson produced carbide in quantities, and in 1895 works were started in England, whilst, at the present time, nearly every country in the world has one or more companies engaged in its manufacture. The production of the gas from the carbide in a safe, simple, and economical manner, evidently presented greater difficulty than was at first anticipated, and many failures resulted in consequence of inexperience before the process was placed on a satisfactory and safe basis.

In 1898 an exhibition of the acetylene light was held at the Imperial Institute, and the Society of Arts appointed a Council to conduct a series of tests of the exhibits, and grant certificates to the exhibitors of those which were found to be satisfactory. This action had the effect of reassuring the public on the question of the safety of the light, with the result that it is now gradually winning its way to favour, especially in rural districts, churches, hotels, railway stations, and country mansions, where either electricity or coal-gas cannot be obtained at reasonable prices, or has not yet been introduced.

As already pointed out in Chapter XXVII. no comparison of the cost of illuminants can be made unless the cost and quality are stated, and therefore each case must be considered by itself; but as a general idea of the cost of coal-gas in England alone, it may be stated that there are over 1000 gas companies charging above 4s. per thousand cubic feet, of which 500 charge above 5s., 200 above 6s., and some even over 10s. per thousand cubic feet.

According to information kindly supplied by Mr. H. E. Baker, managing director of the Acetylene Corporation of Great Britain, the quantity of acetylene produced from 1 lb. of carbide of calcium varies from 5 cubic feet to 5·44 cubic feet. On the basis of 5 cubic feet, to take the lowest figure, this is equal to 250 candle-power per pound of carbide per hour, which is obtainable in quantities at 2d. To produce an equal degree of illumination by means of 16 candle-power gas when burnt in a flat-flame burner, about 90 cubic feet per hour are required, which, at 3s. per thousand cubic feet, will cost 3¼d. Of course, if the comparison is made against the Welsbach incandescent mantle, the cost for gas alone will be about one-seventh of that sum, and the comparison, so far as cost of gas is concerned, is in favour of the Welsbach. In those cases, however, where no coal gas is available, these considerations cannot be taken into account. But there are many cases in which the incandescent mantle cannot be employed with advantage, quite apart from the question of cost, and these are the cases in which the acetylene will be found of most value. The fact that the acetylene light is now in use for churches, country houses, a hall capable of seating 4000 people, hotels, a military camp, &c., and that the apparatus when fitted up under the direct supervision of the above company is guaranteed for five years, clearly indicates the steady advance which this form of illumination is making in public favour.

In order to produce acetylene gas from carbide of calcium it is necessary that the carbide should be brought into contact with water. Several methods have from time to time been adopted in order to bring the two necessaries into contact, most of which have now been abandoned for one reason or another.

Two methods have, however, survived:—First, arranging the charge of carbide in a generator in such a way that the water attacks it from the bottom (Fig. 213) and gradually encroaches upon it, thereby releasing the gas which is conveyed away to the gasometer, purifiers, service pipes, and burners. This method can be performed automatically if required, in which case the charge is split up into a number of portions, and the water supply to the carbide is automatically controlled so that only one portion is attacked at a time, the gas from which fills the gasometer, and in the ascent of the gasometer (Fig. 214) the water is shut off. When the gas thus produced is used, the gasometer falls and automatically turns on the water to another portion of the carbide, this alternate action continuing until the whole charge of carbide is exhausted. The great advantage of the automatic

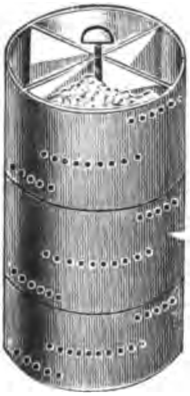

Fig. 213.

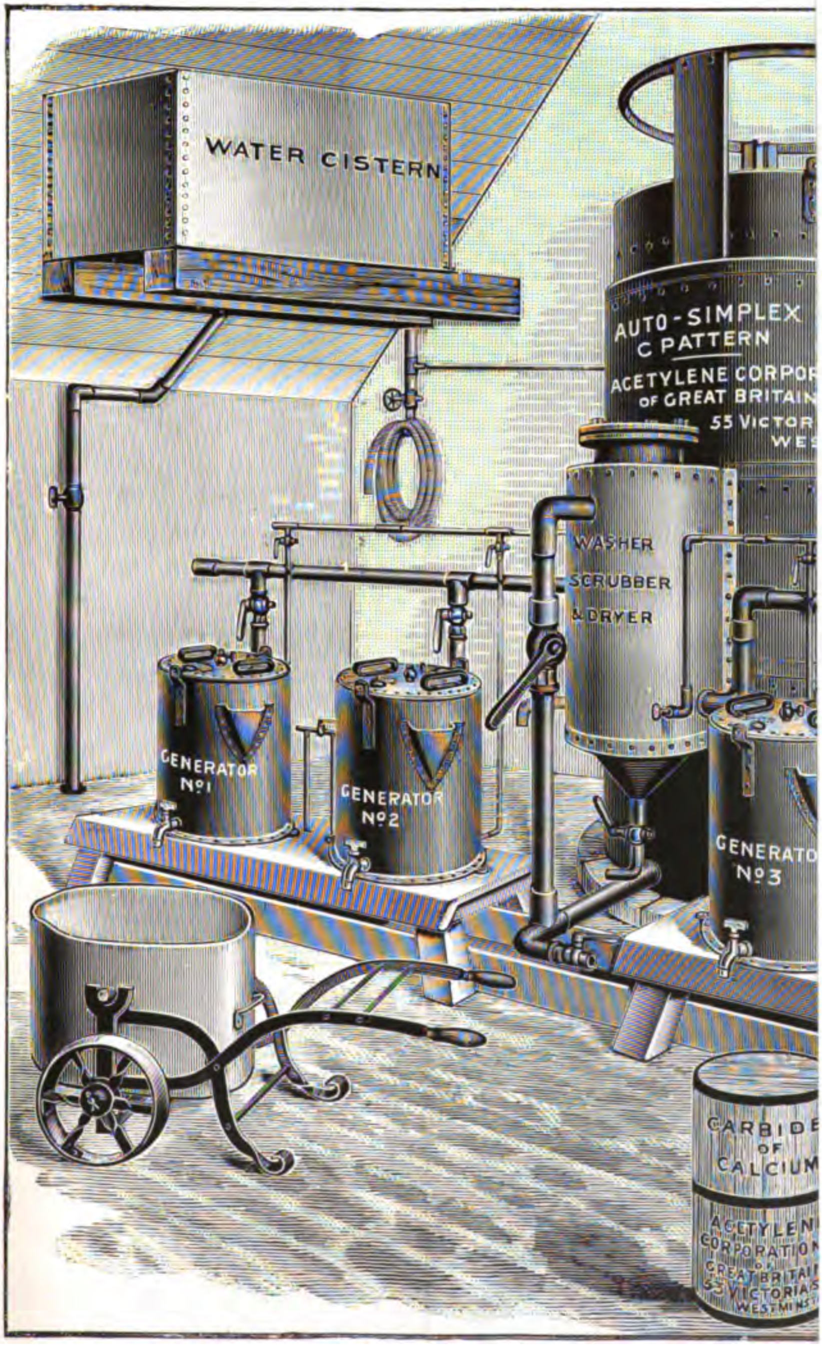

Fig. 214—AUTO-SIMPLEX PLANT FOR THE

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system is the small size of the plant and the consequent economy both in the cost of the plant and the space it occupies. Another and less apparent advantage is that the acetylene gas is always fresh, and its illuminating value is not so much depreciated. It is, of course, evident that this method of production, which is known as the flooding process, can also be performed non-automatically (Fig. 215), that is to say, a constant stream of water can be allowed to flow to the carbide and the whole of the gas collected in a large storage holder. The flooding process when performed in a scientifically-

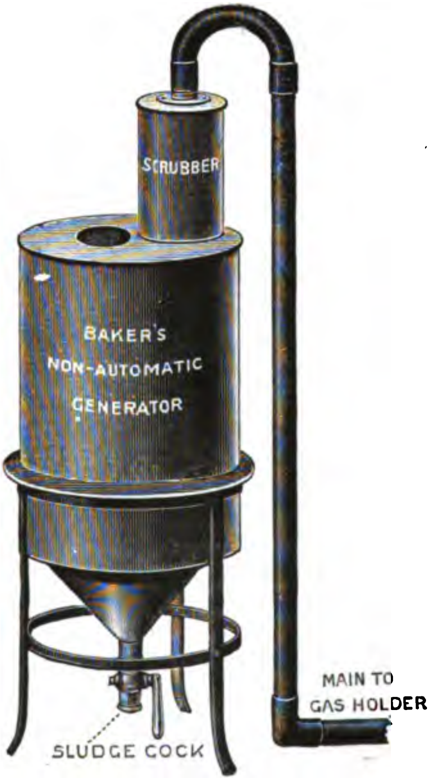

Fig. 215.

constructed apparatus, which is water sealed, and which does not allow of a greater pressure than from 4in. to 6in. on the generating chamber, produces the largest volume of gas from the carbide, some results yielding more than 5 cubic feet to the pound of carbide.

The other process which has survived, and has numerous advocates, is that of throwing small quantities of carbide into a large volume of water, and collecting the gas as it bubbles through the water in a storage holder. The disadvantage of this method is that it cannot with any degree of certainty be performed automatically unless the carbide is broken to gunpowder size, as the lumps of carbide would be almost certain to put the mechanism out of gear. Therefore with such an apparatus it is usual to have a storage holder to accommodate the required amount of gas and throw the carbide into the generator by hand until the holder is full. The gas made in this way in a properly-constructed apparatus is undoubtedly good, but the plant is more expensive than with the flooding process on account of the required storage holder; and there is also a very considerable loss of gas through its being absorbed in the large volume of water in the generator, as the water has to be changed each time and consequently absorbs fresh quantities of gas. The yield of gas from the best generators of this class does not exceed 4¼ cubic feet to the pound.

Having generated the gas by either of these two methods, it has been found by experience that in order to obtain the best results it is necessary to subject the gas to a process of washing, drying, scrubbing, and purifying.

This is partly necessary, owing to the fact that commercial carbide of calcium contains certain impurities in small quantities which would render it unpleasant if burned, in a close room, in the state in which it issues from the generator. In the early days of acetylene this detail was not considered, and consequently many people gave up the use of the gas, thinking that it was poisonous in character.

The process adopted is as follows:—As the gas leaves the generator it is made to bubble through water in fine streams (see Fig. 214). This has the effect of cooling, washing, and freeing it from any any traces of ammonia. From the washer the gas enters the gasometer by an inlet pipe which is *not* connected with

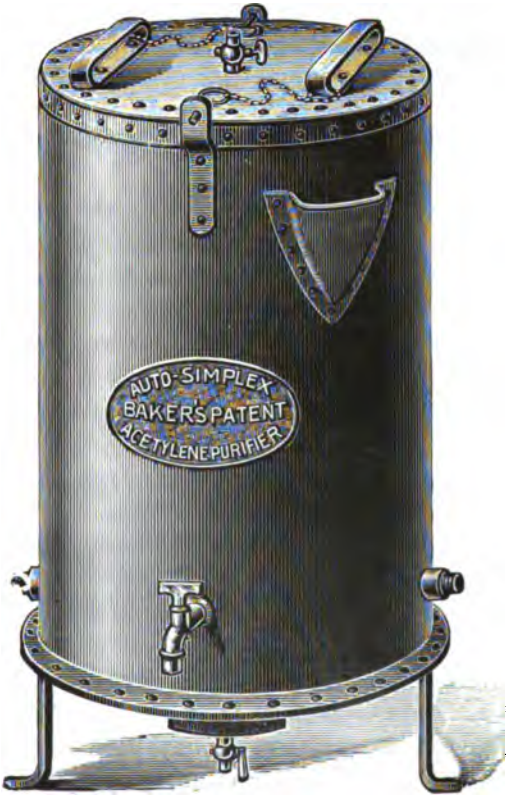

Fig. 216

the gas service to the burners. In its course tothe gasometer the gas has to travel through pipes which are always immersed in the cold water of the gasometer tank, which has the effect of condensing the gas, any condensation dropping back into the washer. By the pressure of the gasometer the gas is forced down the outlet pipe and enters the dryer and scrubber, the latter being absolutely necessary. In fact, the omission of this part of the plant is responsible for the burner troubles, the reason being that where the scrubber is omitted the tiny holes of the burner nipple constitute the first serious resistance to the gas, when the burner really acts as a scrubber, and becomes blocked with the impurities removed from the gas.

The gas, having been scrubbed, is next conveyed to a water-sealed purifier (Fig. 216), which removes from it any traces of phosphuretted hydrogen, and completes the drying of the gas.

The acetylene is now ready for use, and is conveyed by means of mains and connections to the points where light is required, but under no circumstances should lead pipes be used. The best installations are always carried out with steam tubing.

If an acetylene installation is to be really good and useful great attention must be paid to the joints both of the gas service and the gas fittings. The ordinary fittings made for coal-gas are for the most part unsatisfactory, and even the more expensive ones should be supplied with special taps which will stand water pressure; and, so far as possible, ball joints and slide fittings should be avoided, otherwise there will be an unpleasant escape of gas.

It was at an early date discovered that the best form of burner was an atmospheric one, which admitted air at the point of ignition in sufficient quantities to keep the flame from the steatite, while for ordinary purposes a burner such as described on page 204, giving two jets of light which impinge and spread into a flame, is most in favour.

CHAPTER XXX.

AMERICAN EXPERIENCE.

THE most recent account of public lighting in America is that given in a report of the Committee of Light of the Board of Legislation of Cincinnati, U.S.A., from which report the following interesting information has been abstracted:—

"Your committee visited all other systems of lighting under consideration. The arcs were found to be of the type known as open arcs, which throw the greatest amount of light at an angle half way between the vertical and horizontal, or, as stated in electrical circles, at an angle of 45° below the horizontal. The light in the open arc lamps is furnished from the points of carbons between which there is an electric arc, the carbons varying from one-half to five-eighths inch in diameter. These open lamps are hung from 30ft. to 40ft. above the ground, in order to throw the maximum light at a greater distance from the lamp on the street than if they were hung lower.

"It was found, as with all the open arc lamps your committee has seen anywhere, that the large base of the lamp cast a big shadow under the lamp. It was explained to your committee that with the old or open type of arc lamps the carbons burned in the open air, being simply surrounded by a large glass globe to protect the carbons to some extent from the blast of wind. The upper carbon is called the positive, and burns at the tip to a point, with a crater or concave hole in the centre of the end of the carbon, while the lower or negative carbon burns to the form of an evenly round peak. The light being given largely from the upper or positive carbon, and the greater amount of light being given from the crater, or hottest part of the carbon, it will be seen that a large portion of the light cannot be thrown in a horizontal direction on account of the walls of the crater, and must be thrown at an angle of about 45° below the horizontal. It will be noted, therefore, that the higher the lamp is suspended from the ground, within reasonable limits, the better the street illumination produced. The source of illumination, however, being at the carbon points, it is obvious that shadows will be thrown by any obstructions, such as the bottom and frames of the lamp. When the lamp is burning the carbons are about one-eighth of an inch apart, this being the length of the electric arc, and as it is exposed to draughts of air the light is subject to some variation, causing flickering of the lamp on account of the wind.

"It was also stated that uneven and impure spots in the carbons caused a disagreeable flickering, which does not occur in the enclosed form of arc lamp. In the enclosed arc lamp the carbons burn in a small air-tight globe, which is inside of the larger outer globe, and therefore burn in a partial vacuum, in which combustion takes place more slowly, and in which, of course, the wind cannot reach the arc and make it unsteady. In the enclosed arc lamps, no air being present, the carbons burn with almost flat ends, about three-eighths of an inch apart, so that the light is given from the ends of the carbon and from the electric arc between the carbons. There being no crater on the positive carbon, and the carbons being so far apart, the most intense light is thrown in practically horizontal directions, so that a much larger amount of light is thrown at a distance from the lamp than where the open arc lamps are used. The practice is to make the small inner globe of white or opal glass, and when the lamp is burning this entire inner globe becomes bright and becomes the source of light, so that the light, instead of emanating from a point, as it does in the open arc lamps, emanates from a closed globe about 3in. in diameter by 6in. long in the enclosed form of arc lamp. This globe being so much larger than the base of the lamp, or than the frame of the lamp, does not permit any shadows to be cast, and the enclosed form of lamp therefore is not only absolutely steady and free from flickering, due to wind or other causes, but it casts no shadows under the lamp and no shadows from the frame of the lamp. It also throws its light to a greater distance, and the effective illumination of the street throughout its length is therefore very much better than with the open type of lamp. The use of an opal inner globe for the enclosed lamp also does away with the brilliant spot which has been objected to with the open type of lamp as being so dazzling in its effect on the eye.

"Of the enclosed type of arc lamp there are two kinds, known as direct-current or alternating-current enclosed lamps, depending on the kind of electricity which is furnished to said lamps. With the direct-current enclosed lamps the end of the carbons burn almost flat, but not together, because the current always goes from the positive to the negative, and the upper carbon, being positive, is always slightly hollowed out or concave. With the alternating lamp, however, the carbons burn with both carbons absolutely flat on their ends. The result is that the alternating lamp throws a still greater proportion of its light in a horizontal direction than does the direct-current enclosed lamp, and for that reason the alternating form of enclosed lamp is considered more effective for street-lighting purposes, where a large amount of light is wanted from 100ft. to 200ft. or 300ft. from the lamps. In both types of enclosed arc lamps the opal inner globe, on account of its white colour, becomes the source of light, and being so large, a considerable amount of light would naturally be thrown into the air and lost unless reflected. It is the practice, therefore, of companies using inclosed arc lamps to use a reflector, which is attached to the lamp immediately above the glass globe, which reflector has a white porcelain under-surface for reflecting the light. The result of the use of this shade is that the light which would otherwise be lost is thrown to the earth and made useful, and that the illumination under the lamp is absolutely uniform and free from shadow. As the lamps throw a horizontal light, as the brilliant carbon points are enclosed by white glass inner globes, it is the practice in cities where your committee has investigated lighting systems to place the lamps at a distance of only 12ft. or 15ft. instead of 25ft. to 40ft. above the ground, as with the open type of arc lamps. This gives a very brilliant illumination on the street free from shadows, and enables the lamp to be placed below the limbs of trees, so that the foliage does not obstruct the light. The placing of the lamps close to the ground is not objectionable, because the white inner globe protects the eye from the glare so noticeable with the open type of arc lamp.

"The experience of your committee, therefore, in all these cities visited would tend to show that electric lighting of the open type or enclosed lamps gives a better illumination than either gas or gasoline lamps, either of the open-flame type or equipped with incandescent gas burners. The consensus of opinion seems to be that the enclosed arc lamp is superior to, and an improvement on, the open type of arc lamp, and that of the two kinds of enclosed arc lamps the alternating is better than the direct-current type, because a greater portion of the light is thrown in a horizontal direction, and because therefore the general illumination of the street is more uniform. Another advantage of the alternating-current type of lamp is that lamps of 1200 candle-power can be used, if desired, from the same dynamo that furnishes the 2000 candle-power lamps, and therefore by the use of the smaller candle-power lamp a greater number of them can be used at the same cost per year for lighting, enabling the lamps to be placed much closer together. The use of an increased number of lamps, giving the same amount of light more evenly distributed, and at no greater cost, would be an object well worth striving for."

The summarised results of the investigations of the Committee are shown in the accompanying table.

APPENDIX I.

BOARD OF TRADE REGULATIONS, WITH ANNOTATIONS BY THE AUTHOR.

(A), for securing the SAFETY of the PUBLIC, and

(B), for ensuring a proper and sufficient SUPPLY of ELECTRICAL ENERGY.

Definitions.

In the following regulations—

The expression "the Order" means the

The expression "the Undertakers" means the Undertakers for the purposes of the Order.

The expression "consumer's wires" means any electric lines on a consumer's premises which are connected with the service lines of the Undertakers at the consumer's terminals.

The expression "aërial line" means any electric line which is placed above ground and in the open air.

The expression "pressure" means the difference of electrical potential between any two conductors through which a supply of energy is given, or between any part of either conductor and the earth; and—

(*a*) Where the conditions of the supply are such that the pressure may at any time exceed 500 volts if continuous, or 250 volts if alternating, but cannot exceed 3,000 volts, whether continuous or alternating, the supply shall be deemed a high-pressure supply:

(*b*) Where the conditions of the supply are such that the pressure may on either system exceed 3000 volts, the supply shall be deemed an extra high-pressure supply.

The expressions "high pressure" and "extra high pressure" respectively are used in relation to electric lines, conductors, circuits, and apparatus, according to the conditions of the supply delivered through the same or particular portions thereof.

Where these regulations require any metallic body to be "efficiently connected with earth," it shall be connected with the general mass of earth in such manner as will ensure at all times an immediate and safe discharge of electrical energy.

Other expressions to which meanings are assigned in the Order or in the above-mentioned Acts have the same respective meanings in these regulations.

A.—REGULATIONS FOR SECURING THE SAFETY OF THE PUBLIC.

General.

(1) The pressure of a supply delivered to any consumer shall not exceed 250 volts at any pair of terminals, except with the express approval of the Board of Trade. Such approval will only be given for special purposes and on the joint application of the consumer and the Undertakers, and the supply will be subject to such further regulations as the Board of Trade may from time to time prescribe.

(2) The pressure of a supply delivered to a transforming station or to transforming apparatus on a consumer's premises may exceed 250 volts, but shall not exceed the limits of high pressure.

(3) An extra high-pressure supply shall not be given except to distributing stations or other premises in the sole occupation of the Undertakers, and with the written consent of the Board of Trade, and subject to such regulations and conditions as the Board may prescribe.

(4) The maximum working current in any conductor shall not be sufficient to raise the temperature of the conductor or any part thereof to such an extent as to materially alter the physical condition or specific resistance of the insulating covering, if any, or in any case to raise such temperature to a greater extent than 30 deg. Fah. The cross-sectional area and conductivity at joints must be sufficient to avoid local heating, and the joints must be protected against corrosion.

(5) The sectional area of the conductor in any electric line laid or erected in any street after the date of these regulations shall not be less than the area of a circle of one-tenth of an inch diameter, and where the conductor is formed of a strand of wires, each separate wire shall be at least as large as No. 20 standard wire gauge.

(6) All material used for insulating electric lines or apparatus shall be of the best quality, and thoroughly durable and efficient, having regard to the conditions of its use. Suitable provision shall be made for the protection of the insulating material against injury or removal.

If the protection so provided be wholly or partly metallic, it shall be efficiently connected with earth.

(7) Every main shall be tested for insulation after having been placed in position and before it is used for the purposes of supply, the

testing pressure being at least 200 volts, and the Undertakers shall duly record the results of the tests of each main, or section of a main.

(8) The insulation of every complete circuit used for the supply of energy, including all machinery, apparatus, and devices forming part of or in connection with such circuit, shall be so maintained that the leakage current shall not under any conditions exceed one-thousandth part of the maximum supply current; and suitable means shall be provided for the immediate indication and localisation of leakage. Every leakage shall be remedied without delay.

Every such circuit shall be tested for insulation at least once in every week, and the Undertakers shall duly record the results of the testings.

Provided that where the Board of Trade have approved of any part of any electric circuit being connected with earth, the provisions of this regulation shall not apply to that circuit so long as the connection with earth exists.

(9) Every high-pressure conductor laid after the date of these regulations shall be continuously covered with insulating material to a thickness of not less than one-tenth part of an inch, and in cases where the extreme difference of potential in the circuit exceeds 2000 volts, the thickness of insulating material shall not be less in inches or parts of an inch than the number obtained by dividing the number expressing the volts by 20,000.

(10) A high-pressure circuit shall not be brought into use unless the insulation of every part thereof has withstood the continuous application, during one hour, of pressure exceeding the maximum pressure to which it is intended to be subjected in use; that is to say, in the case of every electric line a pressure twice the said maximum pressure, and in the case of every machine, device, or apparatus, a pressure 50 per cent. greater than the said maximum pressure.

The Undertakers shall duly record the results of each test.

(11) Every high-pressure electric line, conductor, or other apparatus shall be protected by a suitable automatic quick-acting cut-off.

Provided that it shall not be incumbent upon the Undertakers to provide such a cut-off for the outer conductor of a concentric main which is, with the approval of the Board of Trade, efficiently connected with earth.

(12) In every case where a high-pressure supply is transformed for the purpose of supply to one or more consumers, some suitable automatic and quick-acting means shall be provided to protect the consumer's wires from any accidental contact with or leakage from the high pressure system, either within or without the transforming apparatus.

(13) A high-pressure electric line shall not be used for the transmission of more than 300,000 watts, or in the case of an äerial line

50,000 watts, except with the consent in writing of the Board of Trade, and efficient means shall be provided to prevent this limit being at any time exceeded.

(14) Where any portion of any electric line, or any support for an electric line is exposed in such a position as to be liable to injury from lightning, it shall be efficiently protected against such injury.

(15) Where any accident by explosion or fire, or any other accident of such kind as to have caused or to be likely to have caused loss of life or personal injury has occurred at any part of any electric line or work, the Undertakers shall give immediate notice thereof to the Board of Trade.

Aërial Lines.

(16) Every aërial line shall be attached to supports at intervals not exceeding 200ft. where the direction of the line is straight, or 150ft. where the direction is curved or where the line makes a horizontal angle at the point of support.

(17) Every support for an aërial line shall be of a durable material, and properly stayed against forces due to wind pressure, change of direction of the line, or unequal lengths of span. The factor of safety shall be for aërial lines and suspending wires at least 6, and for all other parts of the structure at least 12, taking the maximum possible wind pressure at 50 lb. per square foot. No addition need be made for a possible accumulation of snow.

Every support, if of metal, shall be efficiently connected with earth.

(18) All aërial lines shall be attached to insulators, and shall be so guarded that they cannot fall away from the support. Conductors covered with insulating material shall not be attached to the insulators by uninsulated metal binders.

(19) An aërial line shall not in any part thereof be at a less height from the ground than 20ft.*, or where it crosses a street 35ft.,† or within 5ft. measured horizontally, or 7ft. measured vertically from any building or erection other than a support for the line, except where brought into a building for the purpose of supply.

(20) Service lines from aërial lines shall be led as directly as possible to insulators firmly attached to some portion of the consumer's premises which is not accessible to any person without the use of a ladder or other special appliance, and from this point of attachment they shall be enclosed and protected in accordance with the subsequent regulations as to electric lines on the consumer's premises. Every portion of any service line which is outside a building but is within 7ft. from the building shall be completely enclosed in stout india-rubber tubing.

* 18ft. in the case of companies in the provinces.

† 30ft. in the case of companies in the provinces.

(21) Where an aërial line crosses a street, the angle between the line and the direction of the street at the place of crossing shall not be less than 60 deg., and the spans shall be as short as possible.

(22) Where an aërial line crosses, or is in proximity to, any metallic substance, precautions shall be taken by the Undertakers against the possibility of the line coming into contact with the metallic substance, or of the metallic substance coming into contact with the line by breakage or otherwise.

(23) Every high-pressure aërial line shall be efficiently suspended by means of insulating ligaments to suspending wires, so that the weight of the line does not produce any sensible stress in the direction of its length. All suspending wires, if of iron or steel, shall be galvanised.

(24) In the case of any high-pressure aërial line exceeding one-half mile in total length, means shall be provided whereby the pressure may be discharged from any portion of the line erected over or alongside of any building or buildings without loss of time in case of fire or other emergency.

(25) Every aërial line, including its supports and all the structural parts and electrical appliances and devices belonging to or connected with the line shall be duly and efficiently supervised and maintained as regards both electrical and mechanical conditions.

(26) An aërial line shall not be permitted to remain erected after it has ceased to be used for the supply of energy, unless the Undertakers intend within a reasonable time again to take it into use.

Electric Lines other than Aërial Lines.

(27) All conduits, pipes, casings, and street boxes used as receptacles for electric lines shall be constructed of durable material, and where laid under carriageways shall be of ample strength to prevent damage from heavy traffic; and reasonable means shall be taken by the Undertakers to prevent accumulation of gas in such receptacles.

(28) Where any electric line crosses, or is in proximity to any metallic substance, special precautions shall be taken by the Undertakers against the possibility of any electrical discharge to the metallic substance from the line or from any metal conduit pipe or casing enclosing the line.

(29) All metal conduits, pipes, or casings containing any electric line shall be efficiently connected with earth; and shall be so jointed and connected across all street boxes and other openings as to make good electrical connection throughout their whole length.

(30) Where isolated lengths of metal conduit, pipe, or casing are used for the protection of any electric line at road crossings or similar positions, special precautions shall be taken to prevent the possibility of any electrical charging thereof.

(31) Where the conductors of electric lines placed in any conduit are not continuously covered with insulating material, they shall be secured in position, and no unfixed uninsulated material of a conducting nature shall be contained in the conduit. No such conductor shall be at a higher potential than 300 volts.

Adequate precautions shall also be taken to ensure that no accumulation of water shall take place in any part of the conduit, and to prevent any dangerous access of moisture to the conductors or the insulators.

In the case of any such electric lines laid in conduits after the date of these regulations, the insulators shall be so disposed that they can be readily inspected.

(32) Every portion of any high-pressure electric line placed above the surface of the ground, or in any subway not in the sole occupation of the Undertakers, shall be completely enclosed either in a tube of highly insulating material embedded in brickwork, masonry, or cement concrete, or in strong metal casing efficiently connected with earth.

(33) Where any high-pressure electric line is laid beneath the surface of the ground, efficient means shall be taken to render it impossible that the surface of the ground or any neighbouring electric line or conductor shall become charged by leakage from the high-pressure electric line.

Street Boxes.

(34) In addition to the provisions contained in Regulation 27 as to the construction of receptacles for electric lines, the following regulations shall be observed with respect to the construction of street boxes:—

(*a*) The covers of all street boxes shall be so secured that they cannot be opened except by means of a special appliance.

(*b*) The covers of all street boxes containing high-pressure apparatus other than cables shall be connected to strips of metal laid immediately underneath the adjacent roadway, and efficient means shall be taken to render it impossible that the covers or other exposed parts of these boxes, or any adjacent material forming the surface of the street, shall become electrically charged, whether by reason of leakage, defect, or otherwise.

(*c*) Where street boxes are used as transformer chambers, reasonable means shall be taken to prevent as far as possible any influx of water, either from the adjacent soil or by means of pipes, and in the case of any such street box exceeding one cubic yard in capacity, ample provision shall be made, by ventilation or otherwise, for the immediate escape of any gas which may by accident have obtained access to the box, and for the prevention of danger from sparking.

(*d*) All street boxes shall be regularly inspected for the presence of gas, and if any influx or accumulation is discovered, the Undertakers shall give immediate notice to the authority or company whose gas mains are laid in the neighbourhood of the street box.

Transforming Stations.

(35) Transforming stations or points in a system of distribution, in which a high-pressure supply is transformed for the purpose of supply to consumers, and which are not on the consumer's premises, shall be established in suitable places which are in the sole occupation and charge of the Undertakers.

Consumer's Premises.

(36) The Undertakers shall be responsible for all electric lines, fittings, and apparatus belonging to them, or under their control, which may be upon a consumer's premises, being maintained in a safe condition and in all respects fit for supplying energy.

(37) In delivering the energy to a consumer's terminals the Undertakers shall exercise all due precautions so as to avoid risk of causing fire on the premises.

(38) A suitable safety fuse or other automatic disconnector shall be inserted in each service line within a consumer's premises as close as possible to the point of entry, and contained within a suitable locked or sealed receptacle of fireproof construction, except in cases where the service line is protected by fuses in a street box.

(39) All electric lines and apparatus placed on a consumer's premises shall be highly insulated and thoroughly protected against injury to the insulation or access of moisture, and any metal forming part of the electric circuit shall not unless efficiently connected with earth be exposed so that it can be touched. All electric lines shall be so fixed and protected as to prevent the possibility of electrical discharge to any adjacent metallic substance.

(40) Where the general supply of energy is a high pressure supply, and transforming apparatus is installed on a consumer's premises, the whole of the high-pressure service lines, conductors, and apparatus, including the transforming apparatus itself, so far as they are on the consumer's premises, shall be completely enclosed in solid walls, or in strong metal casing efficiently connected with earth and securely fastened throughout.

(41) The Undertakers shall not connect the wires and fittings on a consumer's premises with their mains unless they are reasonably satisfied that the connection would not cause a leakage from those wires and fittings exceeding one ten-thousandth part of the maximum supply current to the premises ; and where the Undertakers decline

to make such connection they shall serve upon the consumer a notice stating their reasons for so declining.

(42) If the Undertakers are reasonably satisfied, after making all proper examination by testing or otherwise, that a leakage exists at some part of a circuit of such extent as to be a source of danger, and that such leakage does not exist at any part of the circuit belonging to the Undertakers, then and in such case any officer of the Undertakers, duly authorised by them in writing, or, if the Undertakers so require, an electric Inspector, may, for the purpose of discovering whether the leakage exists at any part of a circuit within or upon any consumer's premises, by notice require the consumer at some reasonable time after the service of the notice to permit him to inspect and test the wires and fittings belonging to the consumer and forming part of the circuit.

In any case where the Undertakers require the services of an electric Inspector under this regulation they shall pay him the prescribed fee.

If on such testing the officer or the electric Inspector discovers a leakage from the consumer's wires exceeding one-ten-thousandth part of the maximum supply current to the premises, or if the consumer does not give all due facilities for inspection and testing, the Undertakers shall forthwith discontinue the supply of energy to the premises in question, giving immediate notice of the discontinuance to the consumer, and shall not re-commence the supply until they are reasonably satisfied that the leakage has been removed. This regulation shall not affect any power contained in the Order or otherwise enabling the Undertakers to discontinue the supply.

(43) If any consumer is dissatisfied with the action of the Undertakers in refusing to give or in discontinuing or in not re-commencing the supply of energy to his premises, the wires and fittings of that consumer may, on his application and on payment of the prescribed fee, be tested for the existence of leakage by an electric Inspector.

This regulation shall be endorsed on every notice given under the provisions of either of the two last preceding regulations.

Arc Lighting.

(44) All arc lamps shall be so guarded as to prevent pieces of ignited carbon or broken glass falling from them, and shall not be used in situations where there is any danger of the presence of explosive dust or gas.

(45) Arc lamps used in any street for public lighting shall be so fixed as not to be in any part at a less height than 10ft. from the ground.

(46) Arc lamps used in any street for private lighting shall be fixed so as not to be in any part at a less height that 8ft. from the ground,

and shall be so screened as to prevent risk of contact with persons. A cut-off switch, fixed in a suitable locked receptacle, shall be provided for every high-pressure arc lamp, and such switch shall be of such pattern and construction as will provide—

(*a*) That the lamp can by its means be entirely disconnected from the supply circuit.

(*b*) That the switch itself can be safely operated in the dark without special precautions; and

(*c*) That there shall be no danger of any injurious electrical arcing, sparking, or heating being caused by the operation of the switch.

(47.) If the Undertakers make default in complying with any of the preceding regulations, they shall on conviction be liable to a penalty not exceeding £10 for every such default, and to a daily penalty not exceeding £10.

The recovery of a penalty under these regulations shall not affect the liability of the Undertakers to make compensation in respect of any damage or injury which may be caused by reason of the default.

B.—REGULATIONS FOR ENSURING A PROPER AND SUFFICIENT SUPPLY OF ELECTRICAL ENERGY

(1) Forty-eight hours at least before the Undertakers are ready to commence to supply energy through any feeding, charging, or distributing main, they shall give public notice of their intention to commence each supply.*

(2) From and after the time when the Undertakers commence to supply energy through any distributing main, they shall maintain a supply of sufficient power for the use of all the consumers for the time being entitled to be supplied from such main; and such supply shall, except so far as may be otherwise agreed upon from time to time between the† County Council‡ and the Undertakers, be constantly maintained. Provided that, for the purposes of testing, or for any other purposes connected with the efficient working of the undertaking, the Authority by whom the electric Inspector is appointed may give permission to the Uudertakers to discontinue the supply at such intervals of time and for such periods as that Authority may think expedient. When the supply is so discontinued, public

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* Or "serve a notice upon the County Council and the Local Authority" in the case of companies in London.

† Or "the Local Authority and the Undertakers" in the case of old companies in the provinces.

‡ Insert "the Local Authority" in the case of companies in the provinces.

notice shall be* given of such discontinuance, and of the probable duration thereof.

(3) The system of distributing mains shall be so arranged that in case it becomes necessary to stop the supply through any portion of a main for more than one hour, for the purposes of repairs, or for any other reason, the stoppage of supply will in no case exceed in amount a maximum power of 200,000 watts, or extend to the premises of more than eighty consumers, and in the case of every stoppage for more than one hour reasonable notice shall be previously given by the Undertakers to every consumer affected thereby except in cases of emergency.

(4) During the whole of the period when a supply of energy is required to be maintained by the Undertakers in the distributing mains under the Order and these regulations, it shall be maintained at a constant pressure, in these regulations termed the " standard pressure ;" but the standard pressure may be different for different portions of the distributing mains. Provided that the Undertakers shall be deemed to have complied with the requirements of this regulation so long as the pressure does not at any point vary more than 2 per cent. from the corresponding standard pressure in the case of a general supply at high pressure, or 3 per cent. in other cases unless changes in pressure recur so frequently as to cause unsteadiness in the supply.

(5) The standard pressure shall be fixed by the Undertakers, and public notice of the amount of such standard pressure shall be given before the Undertakers commence to supply energy to consumers, and such standard pressure shall not be altered except† with the approval of the County Council, and upon such terms and conditions as‡ the County Council§ may impose, and after public notice has been given, during a period of one month|| of the intention of the Undertakers to apply for such approval. If the County Council refuse to approve such alterations or impose any terms or conditions with which the Undertakers are dissatisfied, the Undertakers may appeal to the Board of Trade, whose decision shall be final.

"Provided that so long as effect is given to the next following

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* " forthwith served upon the County Council and the Local Authority " in the case of old companies in London ; or " the Local Authority " in the provinces.

† " By permission of the Board of Trade " in the case of new schemes by Local Authorities in the provinces.

‡ "Board of Trade " in cases cited in (2).

§ or " Local Authority " in the provinces.

|| " to the County Council " in London ; or " the Local Authority " in the provinces ; " in such manner as the County Council " or " Local Authority " may require. In the case of new schemes by Local Authorities in the provinces, read " Board of Trade."

regulation the Undertakers shall not be bound, under this regulation or any regulation corresponding thereto, previously made, to comply with any condition which has been or may be imposed thereunder, the effect of which is to prohibit any change in the pressure of the supply to any premises except with the consent of the consumer."

(6) Before commencing to give a supply of energy to any consumer, the Undertakers shall declare to such consumer the constant pressure at which they propose to supply energy at his terminals. The pressure so declared at any pair of a consumer's terminals shall not at any time be altered or departed from except in consequence of any authorised alteration of the corresponding standard pressure. In the case of a transformation of energy on the consumer's premises, the Undertakers shall give the consumers the choice of a supply at either of two different pressures, one of which shall be approximately half the other, and in such case the pressure so chosen by the consumer shall be the declared constant pressure.

"But where the consumer withholds his consent after the Undertakers have offered to comply with the general terms and conditions imposed by the Local Authority,* and, if not required to do so under those terms and conditions, also to pay the reasonable cost of or incidental to the change (including compensation for any loss or damage incurred in consequence of the change), the Undertakers may appeal to the Board of Trade, and that Board may, if they think fit, give their consent to the change on such terms and conditions as they impose, and the consent of the Board so given shall for the purpose of this regulation have the same effect as the consent of the consumer.

The Board of Trade may, if they think it necessary in any case, refer to a single arbitrator appointed by them to determine what terms and conditions it would be proper to impose under this provision in case the consent of the Board is given.

Any such arbitration shall be subject to the like provisions as an arbitration in pursuance of a special Act under Part I. of the Board of Trade Arbitrations, &c., Act, 1874, and shall also be subject to the provisions of the Arbitration Act, 1889, as if the arbitration were pursuant to a submission, except that the powers under the last-mentioned Act with respect to the costs of the reference and award shall be exercised by the Board of Trade instead of by the arbitrator.

Provided that no change shall be made in the pressure of the supply to any premises which at the date of these regulations are supplied with energy by the Undertakers except with the consent of the consumer.*

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* In the case of Local Authorities in the Provinces read "Board of Trade" instead of "Local Authority," and in the case of London read "County Council."

(7) The variation of pressure at any consumer's terminals shall not under any conditions of the supply which the consumer is entitled to receive exceed 4 per cent. from the declared constant pressure.

(8) If the Undertakers make default in complying with any of these regulations as to supply, they shall, subject to the provisions of the Order, be liable on conviction to a penalty not exceeding £5 for every such default, and to a daily penalty not exceeding £5.

These regulations are made subject to the power of the Board of Trade to make such further or other regulations as they may think expedient; and nothing in these regulations shall be construed to authorise the Undertakers to lay any electric line or work their undertaking otherwise than in accordance with the Order and the principal Act, or to supply energy otherwise than by a system for the time being approved of by the Board of Trade under the Order.

These are the regulations and conditions for securing the safety of the public and for ensuring a proper and sufficient supply of electrical energy, made by the Board of Trade under the provisions of the Electric Lighting Acts, 1882 and 1888, and of the
, referred to in the letter from the Board of Trade
to the , of the day of
one thousand eight hundred and ninety- , and that date shall
be deemed to be the date of these regulations.

Assistant Secretary,
Board of Trade

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* This proviso is deleted in new schemes.

APPENDIX II.

ELECTRIC LIGHTING ACTS, 1882 TO 1890.

RULES MADE BY THE BOARD OF TRADE WITH RESPECT TO APPLICATIONS FOR LICENCES AND PROVISIONAL ORDERS, &C.

Consent of Local Authorities.

Rule I.—No application for a licence or for the renewal of a licence will be entertained unless proof of the consent to such application of every local authority having jurisdiction within the proposed area of supply is given to the Board of Trade.

Rule II.—No application for a provisional order (other than an application from the local authority of the district) will be entertained by the Board of Trade unless proof of the consent of every local authority having jurisdiction within the proposed area of supply to the grant of the order, or a request from the applicants asking the Board of Trade to dispense with the consent of such local authorities as have not consented and giving the reasons for such request, is deposited with the Board of Trade within the time limited for proving compliance with the provisions of the Electric Lighting Acts and these rules.

Rule III.—At the time of proving the consent of the local authority to an application for a licence or renewal of a licence or to the grant of a provisional order, the applicants must deposit with the Board of Trade copies of any agreement entered into with the local authority relating to such consent.

Rule IV.—Where the consent of any local authority is required to any application for a licence or the renewal of a licence or to the grant of a provisional order, such consent must be given by a resolution passed at a meeting of the local authority held after previous notice of the same and of the purpose thereof has been given in the manner in which notices of meetings of such local authority are usually given; and the fact that such a resolution was duly passed must be proved by a certificate signed by the secretary or clerk to such local authority reciting copies of the notice and of the resolution, and declaring that the notice was duly given and the resolution duly passed.

Notices.

Rule V.—Any local authority, company, or person intending to apply for a licence or provisional order must at the time of lodging their memorial with the Board of Trade in the case of a licence, and on or before the 1st November in the case of a provisional order, give notice in writing of their intended application to every local authority, company, or person authorised to supply electricity under statutory powers within the district to which the proposed application refers.

Rule VI.—Except in the case of an application by the local authority for the district a provisional order will not be granted by the Board of Trade except to the body or person by whom the notice required by section 4, sub-section 1, of the Electric Lighting Act, 1882, was given.

Rule VII.—In any case where a local authority, company, or person is required by the Acts to give notice to the local authority of the district, "in such manner as the Board of Trade may direct or approve," such notice must be given in writing, and must be served, either by leaving the same at the offices of the said local authority on or before the appointed day or by forwarding the same by post in a registered letter, so that the same would in ordinary course of post be delivered on or before the appointed day.

Application and Deposits.

Rule VIII.—Every application for a licence or provisional order must be made by memorial signed or sealed by, or on behalf of, the applicants, headed with a short title descriptive of the proposed undertaking (corresponding with that at the head of the advertisement hereinafter mentioned, *see* Rule XIII.), addressed to the Board of Trade. With the memorial must be deposited six copies of the draft licence or order, as applied for, with the schedule or schedules (if any) referred to therein.

Rule IX.—The deposited copies of the draft licence or order must be in print. They must be printed on one side only and each schedule annexed must begin a new page.

The names and addresses of the parliamentary agents or solicitors for the licence or order must be printed on the outside of the draft.

There must be a notice at the end of the draft stating that objections are to be made by letter addressed to the Board of Trade, marked on the outside of the cover enclosing it "Electric Lighting Acts," and that such letter is to be sent to the Board of Trade in the case of a provisional order on or before the 15th January next ensuing, and in the case of a licence within two months from the date of the newspaper containing the first advertisement of the application, and that a copy of such objections is to be forwarded to the parliamentary agents or solicitors for the licence or order.

The draft must contain among other things—

1. The address and description of the applicants.

2. A description of the proposed area of supply.

*3. A statement of the purposes for which a supply is to be given, viz., any or all of the public or private purposes specified in section 3 of the Electric Lighting Act, 1882.

*4. Provisions concerning the breaking up of streets, railways, and tramways, where powers are sought to be obtained by the licence or order for those purposes.

*5. Conditions of supply.

*6. Provisions for securing the safety of the consumer and of the public from injury by shock, fire, or otherwise.

*7. Provisions for enforcing the performance by the undertakers of their duties in relation to the supply of electricity and for the revocation of the licence or order where the undertakers fail to perform such duties.

The applicants must also deposit a sufficient number of printed copies of the draft licence or order at offices in London and within the proposed area of supply to be specified in the advertisement hereinafter mentioned—see Rule XIII.—such copies to be there furnished to all persons applying for them, at a price of not more than one shilling each.

Rule X.—The applicants must also deposit at the Board of Trade a published map of the district on a scale of not less than 6in. to a mile, or if there is no published map, then the best map procurable, showing the boundaries of the proposed area of supply, and the streets in which it is proposed that electric lines should be laid down within a specified time—

They must also deposit a copy of the said map for public inspection—

> In England or Ireland, in the office of the clerk of the peace for every county, riding, or division, and of the local authority of every district.
>
> In Scotland, in the office of the principal sheriff clerk, for every county, district, or division, and of the local authority of every district

in which the proposed area of supply or any part thereof is situate.

Such deposits must be made in the case of a licence when the memorial is lodged, and in the case of a provisional order on or before the 30th November.

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* These particulars must not be set out at length in draft orders, but must be provided for by the incorporation of the Electric Lighting (Clauses) Act, 1899.

Rule XI.—There must also be deposited with the memorial—

1. A list of the local authorities in whose districts the area of supply is situate.

2. A list of the local authorities, companies, or persons (if any) authorised to supply electricity under statutory powers within the area of supply.

3. A list of the streets not repairable by a local authority and of the railways and tramways (if any) which the applicants propose to take powers to break up.

4. A list of the canals and navigable rivers (if any) within the proposed area of supply.

5. In the case of an application by a local authority, a statement of particulars on the following points:—

(*a*) The sums proposed to be expended on the undertaking:
(*b*) Whether it is proposed to raise a loan for the purposes of the undertaking:
(*c*) The present rateable value of the district:
(*d*) The amount of existing indebtedness and borrowing powers of the applicants for all purposes; and
(*e*) The amount of existing rates in the pound.

In the case of an application otherwise than by a local authority, a statement of the capital proposed to be expended and employed in connection with the undertaking, and the mode in which such capital is to be provided.

6. If the applicants are a company incorporated under the provisions of the Companies Acts, a copy of the memorandum and articles of association.

7. A fee of £50 by cheque, payable to an "Assistant Secretary of the Board of Trade," to cover ordinary expenses. If, in consequence of inquiries or otherwise, additional expense is incurred, the amount will be charged to the applicants and must be paid by them in addition to the ordinary fee.

Applications under Section 13 *of Electric Lighting Act*, 1882.

Rule XII.—Where the undertakers under any licence, order, or Special Act desire the written consent of the Board of Trade under section 13 of the Electric Lighting Act, 1882, to enable them to break up any street not repairable by a local authority or any railway or tramway which they are not empowered to break up under such licence, order, or Special Act, application for such consent must be made by memorial, and the memorial must specially request such consent, and must describe accurately the street, railway, or tramway which they propose to acquire power to break up.

Procedure.

Rule XIII.—Applicants for a licence or provisional order must proceed as follows, subject in the case of a licence to the application having been previously entertained by the Board of Trade, *vide* Rule I.:—

They must publish notice by advertisement of their application, or in the case of a provisional order, of their intended application, and every such advertisement must contain the following particulars:—

1. The objects of the application.
2. The address and description of the applicants.
3. A description of the proposed area of supply.
4. The names of the streets in which it is proposed that electric lines should be laid down within a specified time.
5. A list of the streets not repairable by a local authority and of the railways and tramways (if any) which the applicants propose to take powers by the licence or order to break up.
6. The address of an office in London, and another office within the proposed area of supply, at which printed copies of the draft licence or order when applied for, and of the licence or order when made, can be obtained at a price of not more than one shilling each.

The advertisement must be headed with a short title, descriptive of the undertaking (corresponding with that at the head of the memorial), and it must state that every local or other public authority, company, or person desirous of bringing before the Board of Trade any objection respecting the application must do so by letter addressed to the Board of Trade, marked on the outside of the cover enclosing it, "Electric Lighting Acts," in the case of a provisional order on or before the 15th January next ensuing, and in the case of a licence within two months from the date of the newspaper containing the first advertisement, and that a copy of such objection must also be forwarded to the parliamentary agents or solicitors for the licence or order.

The advertisement must be inserted once at least in each of two successive weeks in one and the same newspaper, published and circulating in the proposed area of supply, or in such other newspaper as the Board of Trade may direct; and once at least in the London, Edinburgh, or Dublin Gazette, accordingly as the proposed area of supply is situate in England, Scotland, or Ireland.

Rule XIV.—If any local or other public authority, company, or person desires to bring before the Board of Trade any objection respecting an application for a licence or a provisional order, they must do so by letter addressed to the Board of Trade, marked on the outside of the cover enclosing it, "Electric Lighting Acts," in the case of a provisional order on or before the 15th January next ensuing, and in the case of a licence within two months from the date of the newspaper containing the first advertisement of the application. A copy of the objection must also be served upon the parliamentary agents or solicitors for the licence or order. If any local or other public authority, company, or person desires to have any clauses or other amendments inserted in the licence or order, they must deliver the same to the Board of Trade, and also to the parliamentary agents or solicitors for the licence or order, on or before the time limited for bringing objections.

Rule XV.—When a licence or provisional order has been granted by the Board of Trade and delivered to the applicants, they must forthwith deposit printed copies for public inspection in the offices specified in Rule X., and must supply copies to all persons applying for the same, at a price of not more than one shilling each, and must further publish the same as the Board of Trade may direct.

Rule XVI.—Where in a licence or provisional order granted by the Board of Trade a deposited map is referred to, the promoters must within one month from the grant of the licence or order deposit at the Board of Trade a published map on a scale of not less than six inches to a mile, or if there is no published map then the best map procurable showing the area of supply coloured to correspond with the description in the licence or order. The map must be mounted on linen, and must be certified as correct as regards their respective districts by the clerk or surveyor to every local authority having jurisdiction within the area of supply.

Special Provisions as to Provisional Orders.

Rule XVII.—In the case of provisional orders the following additional regulations must be observed:—

1. The advertisements must be inserted in October or November.

2. A copy of the advertisement must be deposited on or before the 30th November at the Board of Trade and at the offices specified in Rule X.

3. The memorial must be lodged on or before 21st December.

4. The parliamentary agents or solicitors for the order must be prepared to prove compliance with the provisions of the Acts and these rules by the 15th January, and all such proofs must be completed on or before the 22nd February. Six days' notice will be given of the day and hour at which such agents or solicitors are to attend for the purpose at the Board of Trade, and printed forms of proof will accompany the notice. These forms must be filled up and brought with the requisite documents to the Board of Trade at the time fixed for receiving proof.

The Board of Trade,
30th July, 1900.

COURTENAY BOYLE,
Secretary.

NOTE.—When applications for provisional orders authorising the supply of electricity within the district of any local authority are received by the Board of Trade from such local authority, and also from any other authority, company, or person, the Board of Trade will give a preference to the application of the local authority of the district in every case where, in the opinion of the Board of Trade, no special circumstances exist which render such a preference inexpedient.

In cases of applications for a licence, renewal of licence, or provisional order, to which objection is made by any person locally interested, the Board of Trade will, if they consider it expedient, hold a local inquiry, of which due notice will be given.

These Rules are in addition to any requirements relating to applications for provisional orders which are contained in the Standing Orders of Parliament.

APPENDIX III.

PROVISIONAL ORDER.

(SESSION .)

PROVISIONAL ORDER

Granted by the Board of Trade under the Electric Lighting Acts, 1882 and 1888* to (*name of Undertakers*)
in respect of (*name of borough or district in which the area of supply is situated*).

1. This Order may be cited as the
Electric Lighting Order, 19 .

2. The provisions contained in the Schedule to the Electric Lighting (Clauses) Act, 1899 (with the exception of sections 83 and 84 of that schedule)†, are incorporated with and form part of this Order.

3. The Undertakers for the purposes of this Order and within the meaning of section 2 of the Schedule to the Electric Lighting (Clauses) Act, 1892, are the‡

4. The area of supply for the purpose of this Order and within the meaning of section 4 of the schedule to the Electric Lighting (Clauses) Act, 1899, shall be the area which is described in the First Schedule to this Order, and is more particularly delineated on the map deposited together with this Order at the Board of Trade by the Undertakers, and signed by an assistant secretary to the Board of Trade.

5.§ Subject to the provisions incorporated with this Order, the Undertakers are specially authorised by this Order to break up the streets not repairable by the local authority which are mentioned in the Second Schedule to this Order, and the railways and tramways which are also mentioned in that Schedule.

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* In Scotch Orders add "and the Electric Lighting (Scotland) Act, 1890."

† In Scotch Orders section 84 only, in Irish Orders section 83 only must be excepted.

‡ A company registered under the Companies Acts should be so described, and the address of the registered office should be added.

§ *See* section 12 of the Schedule to the Electric Lighting (Clauses) Act, 1899.

6. The streets and parts of streets throughout which the Undertakers are to lay down suitable and sufficient distributing mains for the purposes of general supply within a period of two years after the commencement of this Order, as mentioned in section 21 of the Schedule to the Electric Lighting (Clauses) Act, 1899, are those mentioned in the Third Schedule to this Order.

7. The maximum prices which may be charged by the Undertakers as mentioned in section 32 of the Schedule to the Electric Lighting (Clauses) Act, 1899, are those stated in the Fourth Schedule to this Order.

8.* The sum to be deposited or secured in pursuance of section 5 of the Schedule to the Electric Lighting (Clauses) Act, 1899 is pounds.

9. This Order shall come into force upon the day when the Act confirming this Order is passed, and that day, for the purposes of the Electric Lighting (Clauses) Act, 1899, shall be the commencement of this Order.

[N.B.—Where an Order is granted to a Company or person having overhead wires already installed, a clause will be inserted providing for their removal except in special circumstances.]

FIRST SCHEDULE.

† Area of supply—

SECOND SCHEDULE.

List of streets not repairable by the local authority, railways, and tramways, which may be broken up by the Undertakers in pursuance of the special powers granted by this Order.

(a) Streets:
(b) Railways:‡
(c) Tramways:

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* This provision is not required in the case of an Order granted to a local authority.

† Where the area of supply consists wholly of recognised areas of Government, such as boroughs, districts, or parishes, it will be described accordingly. In other cases detailed boundaries must be inserted, and a provision added, that in case of difference between the description in the Schedule and the area as delineated on the deposited map, the latter is to prevail.

‡ In ordinary cases the level crossings must be specified. In the case of a light railway or other railway running along the highway on the level, the length and position of the railway must be described.

THIRD SCHEDULE.

List of streets and parts of streets throughout which the Undertakers are to lay down suitable and sufficient distributing mains for the purposes of general supply, within a period of two years after the commencement of this Order—

FOURTH SCHEDULE.

MAXIMUM PRICES.

In this schedule—

The expression "unit" shall mean the energy contained in a current of one thousand ampères flowing under an electromotive force of one volt during one hour.

SECTION 1.

Where the Undertakers charge any consumer by the actual amount of energy supplied to him, they shall be entitled to charge him at the following rates per quarter:—For any amount up to twenty units, ten shillings; and for each unit over twenty units, sixpence.

SECTION 2.

Where the Undertakers charge any consumer by the electrical quantity contained in the supply given to him, they shall be entitled to charge him according to the rates set forth in section 1 of this schedule, the amount of energy supplied to him being taken to be the product of that electrical quantity and the declared pressure at the consumer's terminals, that is to say, such constant pressure at those terminals as may be declared by the Undertakers under the Board of Trade regulations.

MODEL DESCRIPTIONS OF ELECTRICITY SUPPLY SYSTEMS.

NOTE.—*The parts which are inapplicable should be struck out.*

(1) A continuous current direct supply at a constant pressure not exceeding............volts.

(2) A continuous current direct supply at a constant pressure not exceeding............volts across the outer conductors of a three-wire system, the intermediate conductor being, with the approval of the Board of Trade, connected with earth at the generating station, but insulated at all other parts.

(8) A high-pressure continuous current supply at a pressure not exceeding............volts to sub-stations from which will be given [*here quote* (1) *or* (2), *and describe mode of transformation*].

(4) A high-pressure alternating current............phase supply at a frequency of not less than............complete periods per second, and at a pressure not exceeding............volts to

(*a*) transformers placed in street-boxes;

(*or*) in sub-stations;

(*or*) in some cases, on consumers' premises, but mainly in sub-stations:

(*or*) (*b*) rotary converters, placed in sub-stations.

(5) The sub-stations will be erected above ground wherever possible, but where necessarily under ground, they will be constructed in accordance with plans submitted to the Board of Trade, and the maximum power supplied to any such sub-station will not exceed 75 kilowatts without the written consent of the Board of Trade.

(6) From the transformers or rotary converters distributing mains will be laid for an alternating current supply at a frequency of not less than............complete periods per second, and at a constant pressure not exceeding............volts or for [*quote* (1) *or* (2)].

(7) The maximum power supplied to any transformer placed singly in a street-box will not exceed 30 kilowatts, and the vacant space within the box will be so restricted as to prevent danger from explosion.

(8) The metallic portions, other than the conductors, of every transformer will be efficiently connected with earth.

(9) At all times when the power supplied to any rotary converter in any sub-station exceeds............kilowatts, an attendant will be constantly on duty in that station.

MAINS.

The feeder mains to sub-stations will be

The distributing mains of the low-pressure network will be

........................insulated
lead sheathed
steel armoured
laid directly in the ground
separate
concentric throughout, the external conductor being, with the approval of the Board of Trade, connected with earth at the generating station, but insulated at all other parts.
two-core
three-core
drawn into
laid in
............pipes

..................conduits
..................troughs
filled in solid with..................
bare conductors supported on insulators in concrete conduits.

Where the mains cross roads they will be drawn into iron pipes.

Efficient means will be taken to keep all pipes and conduits free from water and gas.

All test and joint-boxes and transformer-boxes will be of metal which will be in good electrical connection with the armouring of the mains on each side.

APPENDIX IV.—CARCEL LAMP.

TABLE FOR ASCERTAINING THE WEIGHT OF OIL BURNED PER HOUR FROM OBSERVATION OF THE TIME OCCUPIED IN BURNING TEN GRAMMES.

Time required to burn 10 grms. of oil.		Rate of consumption per hour. Grms.	Relation to the Carcel lamp burning 42 grms. of oil per hour.	Time required to burn 10 grms. of oil.		Rate of consumption per hour. Grms.	Relation to the Carcel lamp burning 42 grms. of oil per hour.
min.	sec.			min.	sec.		
13	0	46·16	1·0989	13	45	43·64	1·0390
13	1	46·09	1·0975	13	46	43·58	1·0377
13	2	46·03	1·0961	13	47	43·53	1·0364
13	3	45·98	1·0947	13	48	43·48	1·0352
13	4	45·92	1·0933	13	49	43·42	1·0339
13	5	45·86	1·0919	13	50	43·37	1·0327
13	6	45·80	1·0905	13	51	43·32	1·0315
13	7	45·74	1·0891	13	52	43·27	1·0302
13	8	45·68	1·0877	13	53	43·22	1·0290
13	9	45·62	1·0864	13	54	43·16	1·0277
13	10	45·57	1·0850	13	55	43·11	1·0265
13	11	45·51	1·0836	13	56	43·06	1·0253
13	12	45·45	1·0823	13	57	43·01	1·0241
13	13	45·40	1·0809	13	58	42·96	1·0228
13	14	45·34	1·0795	13	59	42·91	1·0216
13	15	45·28	1·0782	14	0	42·86	1·0204
13	16	45·22	1·0768	14	1	42·81	1·0192
13	17	45·16	1·0755	14	2	42·76	1·0180
13	18	45·11	1·0741	14	3	42·70	1·0168
13	19	45·06	1·0728	14	4	42·65	1·0156
13	20	45·00	1·0714	14	5	42·60	1·0144
13	21	44·94	1·0701	14	6	42·55	1·0132
13	22	44·88	1·0687	14	7	42·50	1·0120
13	23	44·83	1·0674	14	8	42·45	1·0108
13	24	44·78	1·0661	14	9	42·40	1·0096
13	25	44·72	1·0648	14	10	42·35	1·0084
13	26	44·66	1·0635	14	11	42·30	1·0072
13	27	44·61	1·0621	14	12	42·25	1·0060
13	28	44·55	1·0608	14	13	42·20	1·0049
13	29	44·50	1·0595	14	14	42·15	1·0037
13	30	44·46	1·0582	14	15	42·10	1·0025
13	31	44·39	1·0569	14	16	42·06	1·0013
13	32	44·33	1·0556	14	17	42·01	1·0002
13	33	44·28	1·0543	14	18	41·96	0·9990
13	34	44·23	1·0530	14	19	41·91	0·9978
13	35	44·17	1·0517	14	20	41·86	0·9967
13	36	44·12	1·0504	14	21	41·81	0·9955
13	37	44·06	1·0491	14	22	41·76	0·9944
13	38	44·01	1·0479	14	23	41·71	0·9932
13	39	43·96	1·0466	14	24	41·66	0·9921
13	40	43·90	1·0453	14	25	41·61	0·9909
13	41	43·85	1·0440	14	26	41·57	0·9898
13	42	43·80	1·0428	14	27	41·52	0·9886
13	43	43·74	1·0415	14	28	41·47	0·9875
13	44	43·69	1·0402	14	29	41·42	0·9864

APPENDIX IV. (*continued*).

Time required to burn 10 grms. of oil.		Rate of consumption per hour. Grms.	Relation to the Carcel lamp burning 42 grms. of oil per hour.	Time required to burn 10 grms. of oil.		Rate of consumption per hour. Grms.	Relation to the Carcel lamp burning 42 grms. of oil per hour.
min.	sec.			min.	sec.		
14	30	41·37	0·9852	15	15	39·34	0·9368
14	31	41·33	0·9841	15	16	39·30	0·9357
14	32	41·28	0·9830	15	17	39·26	0·9347
14	33	41·23	0·9818	15	18	39·22	0·9337
14	34	41·19	0·9807	15	19	39·17	0·9327
14	35	41·14	0·9796	15	20	39·13	0·9317
14	36	41·09	0·9785	15	21	39·09	0·9307
14	37	41·04	0·9774	15	22	39·05	0·9297
14	38	41·00	0·9762	15	23	39·00	0·9286
14	39	40·96	0·9751	15	24	38·96	0·9276
14	40	40·91	0·9740	15	25	38·92	0·9266
14	41	40·86	0·9729	15	26	38·88	0·9256
14	42	40·81	0·9718	15	27	38·83	0·9246
14	43	40·77	0·9707	15	28	38·79	0·9236
14	44	40·72	0·9696	15	29	38·75	0·9226
14	45	40·68	0·9685	15	30	38·71	0·9217
14	46	40·63	0·9674	15	31	38·67	0·9207
14	47	40·59	0·9663	15	32	38·63	0·9197
14	48	40·54	0·9653	15	33	38·59	0·9187
14	49	40·49	0·9642	15	34	38·54	0·9177
14	50	40·45	0·9631	15	35	38·50	0·9167
14	51	40·40	0·9620	15	36	38·46	0·9158
14	52	40·36	0·9609	15	37	38·42	0·9148
14	53	40·31	0·9598	15	38	38·38	0·9138
14	54	40·27	0·9588	15	39	38·34	0·9128
14	55	40·22	0·9577	15	40	38·30	0·9119
14	56	40·18	0·9566	15	41	38·26	0·9109
14	57	40·13	0·9556	15	42	38·22	0·9099
14	58	40·09	0·9545	15	43	38·18	0·9090
14	59	40·04	0·9534	15	44	38·14	0·9080
15	0	40·00	0·9524	15	45	38·10	0·9070
15	1	39·96	0·9513	15	46	38·05	0·9061
15	2	39·91	0·9503	15	47	38·01	0·9051
15	3	39·87	0·9492	15	48	37·97	0·9042
15	4	39·82	0·9482	15	49	37·93	0·9032
15	5	39·78	0·9471	15	50	37·89	0·9023
15	6	39·74	0·9461	15	51	37·85	0·9013
15	7	39·69	0·9450	15	52	37·82	0·9004
15	8	39·65	0·9440	15	53	37·78	0·8994
15	9	39·60	0·9430	15	54	37·74	0·8985
15	10	39·56	0·9419	15	55	37·70	0·8975
15	11	39·52	0·9409	15	56	37·66	0·8966
15	12	39·47	0·9398	15	57	37·62	0·8957
15	13	39·43	0·9388	15	58	37·58	0·8947
15	14	39·39	0·9378	15	59	37·54	0·8938

APPENDIX IV. (*continued*).

TABLE FOR FINDING THE RATE OF CONSUMPTION OF SPERM BY TWO CANDLES IN TEN MINUTES FROM OBSERVATION OF THE TIME REQUIRED TO BURN 40 GRAINS.

Time required to burn 40 grains.	Rate of consumption in 10 minutes.	Time required to burn 40 grains.	Rate of consumption in 10 minutes.	Time required to burn 40 grains.	Rate of consumption in 10 minutes.
min. sec.	Grains.	min. sec.	Grains.	min. sec.	Grains.
9 0	44·44	9 41	41·31	10 21	38·65
9 1	44·36	9 42	41·24	10 22	38·59
9 2	44·28	9 43	41·17	10 23	38·52
9 3	44·20	9 44	41·10	10 24	38·46
9 4	44·12	9 45	41·03	10 25	38·40
9 5	44·04	9 46	40·96	10 26	38·34
9 6	43·96	9 47	40·89	10 27	38·28
9 7	43·88	9 48	40·82	10 28	38·22
9 8	43·80	9 49	40·75	10 29	38·16
9 9	43·72	9 50	40·68	10 30	38·10
9 10	43·64	9 51	40·61	10 31	38·03
9 11	43·56	9 52	40·54	10 32	37·97
9 12	43·48	9 53	40·47	10 33	37·91
9 13	43·40	9 54	40·40	10 34	37·85
9 14	43·32	9 55	40·34	10 35	37·80
9 15	43·24	9 56	40·27	10 36	37·74
9 16	43·16	9 57	40·20	10 37	37·68
9 17	43·08	9 58	40·13	10 38	37·62
9 18	43·01	9 59	40·07	10 39	37·56
9 19	42·93	10 0	40·00	10 40	37·50
9 20	42·85	10 1	39·94	10 41	37·44
9 21	42·78	10 2	39·87	10 42	37·38
9 22	42·70	10 3	39·80	10 43	37·32
9 23	42·63	10 4	39·74	10 44	37·26
9 24	42·55	10 5	39·67	10 45	37·21
9 25	42·48	10 6	39·60	10 46	37·15
9 26	42·40	10 7	39·54	10 47	37·09
9 27	42·33	10 8	39·47	10 48	37·03
9 28	42·25	10 9	39·40	10 49	36·98
9 29	42·18	10 10	39·34	10 50	36·92
9 30	42·11	10 11	39·28	10 51	36·87
9 31	42·03	10 12	39·21	10 52	36·81
9 32	41·96	10 13	39·15	10 53	36·75
9 33	41·88	10 14	39·09	10 54	36·70
9 34	41·81	10 15	39·02	10 55	36·64
9 35	41·74	10 16	38·96	10 56	36·59
9 36	41·67	10 17	38·90	10 57	36·53
9 37	41·60	10 18	38·83	10 58	36·47
9 38	41·52	10 19	38·77	10 59	36·42
9 39	41·45	10 20	38·71	11 0	36·36
9 40	41·38				

ADDENDA.

Since the account of the Scott-Snell self-intensifying system was written, the author is informed that in the latest type of the Scott-Snell lamp the gas supply is not interfered with, that is, the gas is burned under normal conditions entirely. A combination gas and air nipple is used which admits the compressed air in parallel jets to the gas jet; together these blow into the burner tube, drawing in additional air as in the ordinary Bunsen burner. The motions and functions of the various parts of the lamp remain the same, but the suction and inlet valve draws air from the surrounding atmosphere instead of gas from the main. This improvement dispenses also with the special reverter or gas controller formerly in the base of the nipple. By making the displacer and the vessel within which it operates in the shape of cylinders, it has been found to increase the radiation at the upper or cool end sufficiently to enable the water formerly used in connection with the lamp to be dispensed with.

TY OF CI OHIO, APRIL 1st, 1901.

	Cost of ea light per l lamp-hour Dollars.	f the Committee on the ctive Illumination.	Opinion of Local Superintendent.
St.	23·77	markable.	Arc lamp best for the business part of the City.
Ch	6·81		Cost of inspectors for these = 5640 dollars per annum.
			Intends to gradually replace all gas lamps with electric arc lamps. Cost of lighting per mile of street 10% more with gas than by arc lamps.
M	er yea 1 to 9(20 ·p. 14 ·p. 28		Price of Welsbach only temporary. If these are adopted price will be increased.
	27		

eight from round. Feet.	Comparing the 16 c.p. Incandescent Electric Lamp with a 15 or 16 c.p. Flat-flame Gas Burner, do you find the light from the former as diffusive as the latter ?	GENERAL REMARKS.
-	No. We should prefer two 8 c.p., if the limit of c.p. is fixed, but I think three 8 c.p. as described extremely good for diffusion.	—
-	Have no incandescent electric street lamps under 50 c.p.	† Painting 1s. 2d. per lamp extra.
-night	—	—
—	—	The most noticeable feature of Chelsea is the irregularity in the distance between the lamps. Were the lighting of the Borough re-organised and lamp-posts fixed at proper intervals a great improvement in the lighting would ensue.
- -	-	The 150 arcs first in use are charged at £19 10s. per annum each; the next 50 at £17 10s., the next 100 at £15, and the remainder and those to be added at £14 10s. each per annum. Experience with incandescent gas lamps (particularly No. 8 burners) not wholly favourable.
10·6	—	—
10	-	Arc lighting is undoubtedly the best, but in narrow streets where there are many streets intersecting the number of arc lights required would be too numerous. Welsbach lamps will be greatly extended this year, those mentioned having been only put up as a trial.

eight from ound. Feet.	Comparing the 16 c.p. Incandescent Electric Lamp with a 15 or 16 c.p. Flat-flame Gas Burner, do you find the light from the former as diffusive as from the latter?	GENERAL REMARKS.
to 14	—	The cost of current is the chief item. We prefer the open-type direct-current arc lamps, owing to their greater efficiency in watts per candle power.
—		—
—	—	The Council have recently decided to alter the whole of the flat-flame burners to incandescent gas burners consuming 3¼ cubic feet per hour, and arrangements are now being made for the necessary alterations to lanterns, fittings, &c.
	Yes.	All street lamps, including arcs, are lighted all night. The glow lamps are switched on and off by an automatic switch worked by the current supplied to the arc lamps which are in three circuits, rectified current, supplied from the electricity works.
12	Yes, and more so in stormy weather when gas flames are unsteady.	Ordinary flat-flame gas burners are used for street lighting generally.
—	Not in the open air	The flat-flame burners are being altered to incandescent at the rate of 20 per week, three-light clusters being substituted for Victorias, and five-light clusters for Lambeths. "C" burners are used.

Height from	Comparing the 16 c.p. Incandescent Electric Lamp with a 15 or 16 c.p. Flat-flame Gas Burner, do you find	GENERAL REMARKS.
		in one of the main thoroughfares through which electric trams run and centre poles used.
11	—	Our present installation of gas lighting with the Welsbach mantles, which has been in operation three or four years, is highly satisfactory. There is no probability of any large extension of the electric lighting in the streets at present.
	Yes.	* 242 arcs for street lighting, seventeen for lighting sea front, and five for lighting wharves.
	—	This town was the first in the kingdom to adopt incandescent gas lighting as a whole. The result has been most satisfactory.
	—	The Welsbach incandescent gas lamps will eventually be used throughout the town, being appreciated for the greater brilliancy and brighter appearance of the streets when lit.
	With clean lamps and good burners the electric has a slight advantage. With white reflectors it has a considerable advantage. Such efficient reflectors cannot be used with flat-flame burners.	Glow lamps on from midnight till 6 a.m. Incandescent gas system being extended.
	—	Also twelve Kitson's petroleum lamps, 1000 c.p. 50 yards apart; 15ft. high.

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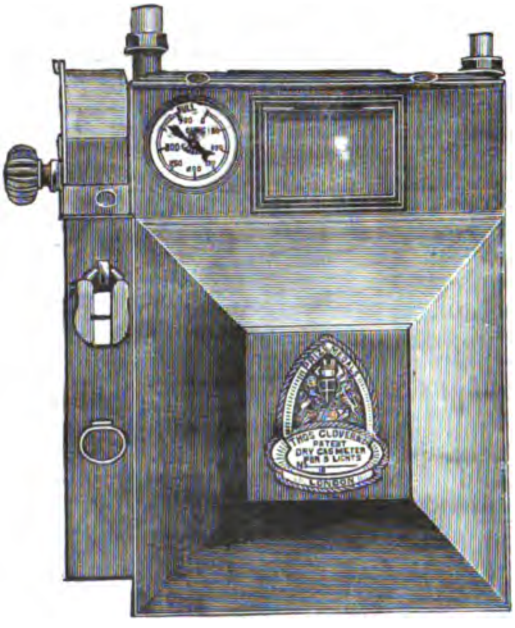

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No
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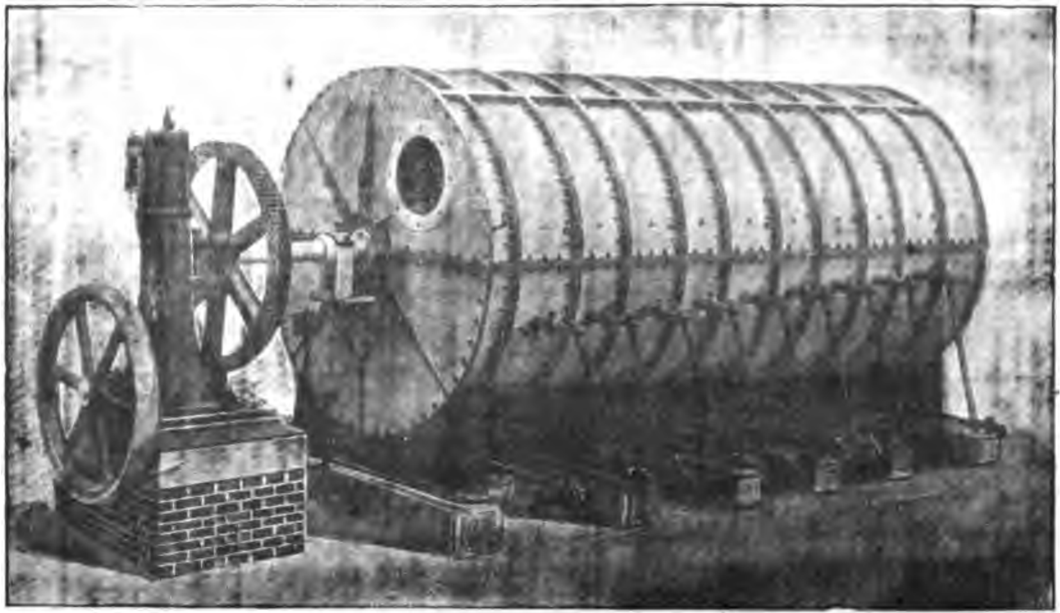

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Giving a Lighting Efficiency of

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With about *20* Cubic Feet of Gas at

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TELEGRAPHIC ADDRESSES:—"Disc, London," "Disc, Manchester," "Disc, Edinburgh," "Disc, Sydney." Telegraphic Codes used:—A 1 and A B C (4th Edition).

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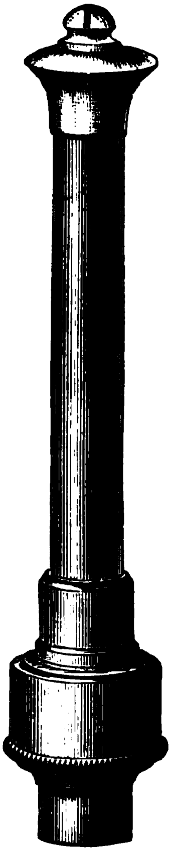

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Works—
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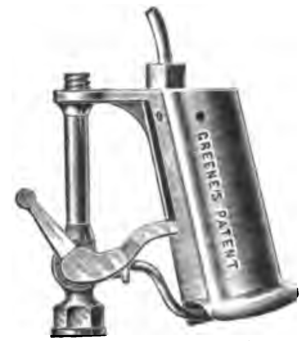
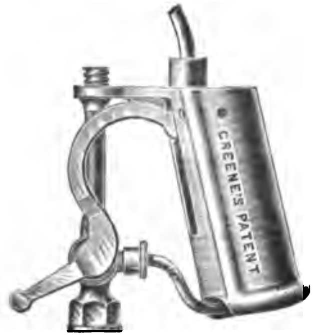
Greene's Patent

CLIMBING LIGHT



LIGHTING A



B EXTINGUISHING

"INSERTIO"

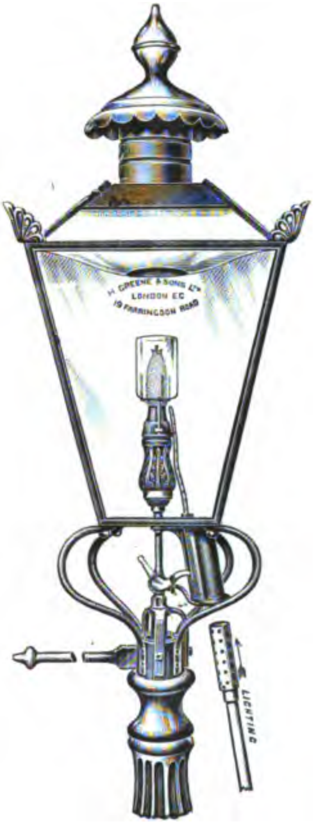
derives its name from the mode of operating the same. The lighted torch is inserted into a cylinder containing a perforated copper tube attached to the gas supply by a cock, which when the torch touches the lever in cylinder at *A*, not only admits Gas to the Climbing Light, but also to the burner, and in such a manner that when the flame reaches the top of the tube the gas supply to the Climbing Light is automatically cut off again, whilst the burner is lit, **an action which is practically instantaneous.**

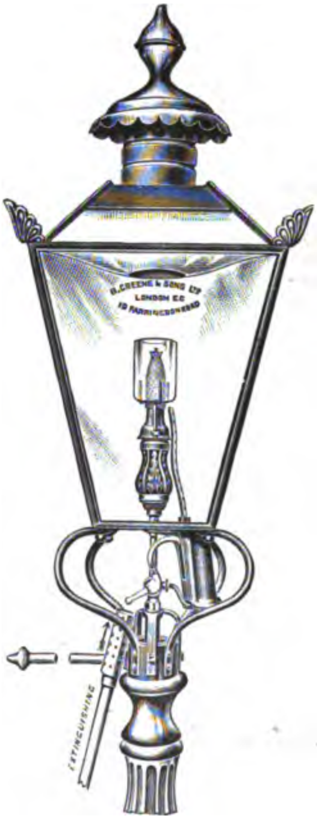
When the burner is to be extinguished, the torch merely touches the opposite end of the cranked lever at *B*. The annexed illustrations show the positions of the lever, from which it will be seen that to light a lamp the torch is inserted at *A*, and to extinguish it, requires a gentle push with torch at *B*, which will place the lever **into its original position, ready again for re-lighting when required.**

The **Insertio** is adaptable to any form of Lamp, to light any number of burners, by one action from the outside of Lamp.

As lamps fitted with our Patent **Insertio** need only be opened for the purpose of cleaning the glass, the protection of mantles is necessarily ensured, and a good many saved per annum, whilst at the same time, flap-doors being done away with entirely, no draughts or accidents to mantles through touching will occur, the saving is very considerable.

Another important saving is the cost of Gas for Bye-passes, the latter being abolished. At the low estimate of one-third cubic foot per hour, the saving will be from **5s.** to **7s. 6d.** (according to price charged for Gas) per annum per burner, practically saving the cost of the **Insertio** in twelve months in gas not used.





The adoption of our Patent Apparatus excludes Wind, Rain, and Dust from the Lamp, the inside glasses keep clean much longer, and are much more easily cleaned, as there are no Bye-pass or other obstructions.

The Gas is lit instantaneously by Lamplighter's ordinary torch.

The **Insertio** is in use in many towns, and has proved a great success. It is strongly made in Brass and Copper as illustrated, and the Cost complete is no more than the cost of an ordinary Lantern-cock and Bye-pass to the burner.

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